DEPARTMENT OF TRANSPORTATION

Flagger Operations: Investigating Their Effectiveness in Capturing Driver Attention

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16. Abstract (Limit: 250 words)

This two-pronged (driving simulation and field study) investigation of driver behavior in work zones contributes basic and applied knowledge to our understanding of work zone safety. In the driving simulator study, a fully interactive PC-based STISIM driving simulator was used to test the effectiveness of roadway elements designed to capture and sustain the attention of drivers in flagger-operated work zones. The participants were 160 licensed drivers from four age groups: 18-24, 32-47, 55-65, and 70+ years of age. Each participant drove each of the three conditions in counterbalanced order. The driving simulator study revealed that the new set of elements is more effective than the elements currently used to reduce driving speeds on the approach to a flagger-controlled work zone. No difference in mean driver speed was found in response to the sign with an LED presence. The dynamic speed display coupled with the horn is more effective than the dynamic speed display alone. The cognitively engaging elements identified as effective in the driving simulator study were tested in two field operational tests. The field tests revealed that all but one of the elements identified in the experimental driving simulator study were effective. In particular, the findings revealed that a combination of the speed trailer and horn barrel are effective in reducing the overall speed of vehicles approaching the field study work zone. The field test revealed that the new experimental layout practically eliminated high-speed outliers in addition to its success in reducing driver approach speed to the flag operator.

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FLAGGER OPERATIONS: INVESTIGATING THEIR EFFECTIVENESS IN CAPTURING DRIVER ATTENTION

FINAL REPORT

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EXECUTIVE SUMMARY

INTRODUCTION

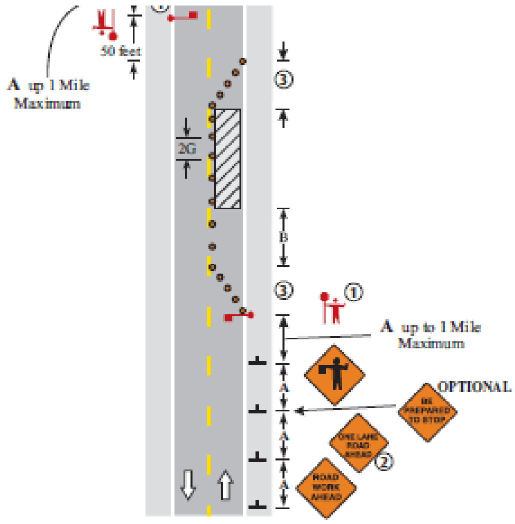
The objective of the current study was to (1) use a driving simulator to test simulated roadway elements to determine their effectiveness in capturing driver attention and fostering compliance in work zones and then (2) in a field test evaluate the on-road effectiveness of the elements identified in the driving simulation study. This two-pronged (driving simulation and field study) investigation of driver behavior in work zones contributes basic and applied knowledge to our understanding of work zone safety.

DRIVING SIMULATION EXPERIMENT

Method

One hundred and sixty licensed drivers from four distinct age groups participated in the driving simulation study. There were 40 participants in each of the four age groups—younger (18 to 24 year olds), middle age (32 to 47 year olds), older (55 to 65 year olds), and seniors (70 years or older). There were 20 males and 20 females within each age group. All 160 participants were licensed drivers. The four age groups included drivers from the metro and non-metro regions and each was paid $50 for his or her participation.

In the driving simulation portion of this study, we used a fully interactive PC-based STISIM driving simulator with an automative-style seat that faced a bank of three 21-inch monitors. Three PCs generated the virtual environment presented on the monitors. Participants drove 10 miles on a two-lane bidirectional highway before they encountered the first warning sign in each of the three drives (conditions). The layout of the control condition is shown in Figure 1. The layout of the work zone area and the distance between the warning signs was the same for each of the three conditions; however, the type or content of the warning signs was changed.



Layout of work zone area *control condition*

In the second condition, each participant encountered four sets of warning signs before he or she approached the work zone, with the (1) “ONE LANE ROAD AHEAD”, (2) combined warning signs of “Flagger Ahead” figure and 45-mile speed limit, (3) combined warning signs of 45-mile speed limit and a dynamic speed limit trailer, which indicated the driving speed of the car within a zone (ahead of the trailer), and (4) “BE PREPARED TO STOP” situated 50 feet before portable rumble strips.

In the third condition, flashing LED lights were added to the perimeter of the “ONE LANE ROAD AHEAD” sign and an auditory warning horn sounded when participants exceeded the 45 mph speed limit on their approach to the dynamic speed limit sign.

SUMMARY RESULTS AND DISCUSSION

Analysis of the effectiveness of LED flashing lights

No statistically significant differences in mean speeds were found between the conditions on the approach to the first warning sign, indicating that the LED lights did not contribute to reduced driving speed.

Analysis of the effectiveness of the horn

The results indicate that there is a statistically significant effect of the warning horn on the speed reduction after the dynamic speed limit sign. However, the horn did not have a continued, pronounced effect into the work zone. It is important to remember that the horn is intended to capture the attention of driver outliers in work zones. The results of this analysis reveal that the horn did capture the attention of outlier drivers and led to statistically significant reductions in driving speed in comparison to those driver outliers who did not hear the horn.

The effect of in-lane transverse rumble strips on driver behavior

The results indicate that nine participants left their lane to avoid experiencing the rumble strips for at least one of the conditions. Of the nine, three participants left their lane to avoid the rumble strips in both conditions, while the other six left the lane to avoid the rumble strips only once. If the opposing lane is closed to oncoming traffic, it is not dangerous for drivers to leave their lane in a flagger-controlled work zone. If, however, the opposing lane is not closed to oncoming traffic, then in-lane transverse rumble strips could foster unsafe driving behavior. While this research reveals that rumble strips capture driver attention, the data also reveal that some drivers engage in potentially unsafe driving behavior to avoid the rumble strips.

In summary, we found that the new set of elements is more effective than the elements currently used to reduce driving speeds on the approach to a flagger-controlled work zone. We found no difference in mean driver speed in response to the sign with an LED presence. We found that the dynamic speed display coupled with the horn is more effective than the dynamic speed display alone.

FIELD STUDY

The cognitively engaging elements identified as effective in the driving simulator study were tested in a field operational test.

One field test of the cognitively engaging/attention-grabbing devices in an active work zone was conducted in Spring Valley, MN on CSAH 8. The work zone was managed by Rochester Sand and Gravel which was performing a full-depth reclamation and resurfacing of 4.1 miles of CSAH 8 north of Spring Valley. Data were collected over an eight-day period. During that time, the research team set up and deployed two different work zone layouts alongside the active work zone on one approach. The first, referred to as base, was the minimum standard setup following Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) guidelines. This setup was supplemented with additional radar sensors, manufactured by Smartmicro, to gather data from the approaching vehicles during the base conditions. The second setup deployed, referred to as the experimental layout in this report, included additional signs and attention getting devices (Horn, Rumble Strips, Speed Trailer) identified as effective during the driving simulator experiment. This layout was also instrumented with additional radar sensors and cameras to gather data on the approaching vehicles.

An earlier field test of the new proposed work zone layout in an active work zone was conducted in Pine City, MN on State Highway 70. The work zone was active over the course of four days. Unfortunately, a combination of short work zone working periods as well as low traffic volumes did not allow for the collection of a statistically secure sample of speeds. Interestingly, the results from the two tests are very comparable. This finding reinforces the observations collected and conclusions reached because the two sites were located very far from one other, the data were collected over a different time period, and the sites were operated by completely different work zone crews.

In summary, the field test revealed that all but one of the elements identified in the experimental driving simulator study were effective. In particular, the findings revealed that a combination of the speed trailer and horn barrel is effective in reducing the overall speed of vehicles approaching the work zone.

The portable rumble strips, however, did not generate any significant speed reduction, although a definitive evaluation of the portable rumble strips would have required a test of the strips in isolation and not when placed downstream of the speed trailer. Unfortunately, such an experiment was not in the scope of this study.

Apart from the portable rumble strips, the field test revealed that the new experimental layout practically eliminated high-speed outliers in addition to its success in reducing driver approach speed to the flag operator.

CHAPTER 1: INTRODUCTION

1.1 OBJECTIVE

The objective of the current study was to (1) use a driving simulator to test simulated roadway elements to determine their effectiveness in capturing driver attention and fostering compliance in work zones and then (2) in a field test evaluate the on-road effectiveness of the elements identified in the driving simulation study. This two-pronged (driving simulation and field study) investigation of driver behavior in work zones contributes basic and applied knowledge to our understanding work zone safety.

1.2 INTRODUCTION

Work zone related crashes continue to be a nation-wide concern. One of the key work zone issues involves flagger operations and flagger safety. Previous studies show that the known presence of human workers directly affects driving speed in work zones. However, driver inattention to the presence of human workers (including flaggers) is a primary safety concern. With the increase of work zone related crashes, it is important to identify a warning system that effectively captures and *sustains* driver attention and fosters compliance to minimize work zone fatalities. This study continues the Principal Investigator's previous research on designing transportation environments to facilitate improved driver compliance and performance. The study investigated the effectiveness of a number of prospective "attention-grabbing" work zone elements [chosen for testing in collaboration with the Technical Advisory Panel (TAP)], first in a simulated driving simulation experiment. As part of the driving simulation study, participant drivers were also surveyed to gain insights regarding the participants' moral perspective regarding work zone driving and safety as well as the perceived effectiveness of the tested elements. The elements found to be most effective in the driving simulation experiment were used to test a new work zone warning configuration in the field. This work contributes substantive progress toward facilitating creative resolutions to safety-related issues now present in short-term work zones. A brief overview of the field's literature follows:

Work Zone Collisions: Aside from the most common vehicle-to-vehicle contact, Mohan and Zech (2005) identified five types of work zone collisions. Their examination of New York State Department of Transportation construction projects from 1999 to 2001 determined that the majority of incidents in the work zone could be classified as, a) work space intrusion, b) workers struck by a vehicle inside the work zone, c) flaggers struck by vehicles, d) workers struck by a vehicle entering/exiting the work space, or e) construction equipment struck by vehicle inside work space. Morgan, Duley, and Hancock (2010) found the reduction of taper length in a construction zone to increase the risk of potential collision. The shorter taper design influenced the drivers to navigate closer to the work zone threshold throughout the entire length and also had an effect on braking patterns.

Risk Factors: The most hazardous work zone configurations involve divided roadways with lane closures during low density traffic conditions and a stopped or braking truck or car (McAvoy, Duffy, & Whiting, 2011). This is not the only hazardous scenario. There are many environmental (external) and human based (internal) risk factors associated with work zone accidents. According to Li and Bai (2009), external factors include lighting conditions, weather, vehicle type, and construction features (e.g., road conditions, construction equipment, and workers). Construction features workers when introduced to the roadway environment represent 1/3 of all work zone accidents (Bryden, Andrew & Fortuneiwicz, 1998). Li and Bai (2009) found that poor light conditions contributed a large percentage of fatal crashes as well as the involvement of heavy trucks. Driver characteristics and driver error are considered internal risk factors. Unfortunately, manipulation of natural day light and weather patterns is not a viable route to limiting risk factors. So, the focus is on reducing the internal risk factors.

Driver Characteristics: Gender and age are two large mediating variables in driving studies. Li and Bai (2009) characterized three high-risk driving groups: Male drivers, senior drivers over the age of 64 driving in the afternoon-night hours, and drivers between the ages of 35 and 44 driving during night hours only. These are the groups with a higher probability of fatality in a severe crash. The findings show an important correlation between age and work zone accidents. Four distinct age groups will be tested in the proposed study to account for the age variable.

Driver Error: The majority of work zone accidents are caused by driver error. Drivers misinterpret signage or do not attend to signs and surroundings. Harder and Bloomfield's (in press, 2010, 2008, 2003) four changeable message sign studies have revealed the importance of designing cognitively digestible information in roadway environments that drivers can readily understand and use in various transportation environments. The current study extends the body of knowledge to the area of work zone safety.

1.3 ORGANIZATION OF THIS REPORT

The remainder of this report describes the driving simulation experiment followed by the field study, both conducted to investigate the effectiveness of various roadside/roadway elements in capturing the attention of drivers in work zones. The experiment and findings using a driving simulator will be presented first, followed by the methods and findings of the field study.

The chapters are organized as follows:

- Chapter 2 describes the method used to conduct the simulation experiment and the findings of the simulation experiment. It concludes with a summary of the findings and conclusions of the driving simulation experiment.
- Chapter 3 presents the method and findings of the field study conducted to test the roadway/roadside elements identified as most effective in capturing driver attention in the driving simulation experiment. It concludes with a summary of the findings and conclusions of the field study.
- Chapter 4 summarizes the findings and conclusions of both the driving simulation experiment and the field study.

CHAPTER 2: DRIVING SIMULATION EXPERIMENT AND SURVEY

Method and Findings
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2.1 METHOD OF DRIVING SIMULATION EXPERIMENT

2.1.1 Participants

One hundred and sixty licensed drivers participated in this study. The breakdown of these participants in terms of age and gender is shown in Table 2.1.

Table 2.1 Breakdown of participants by age and gender

Age	Male	Female	Total
Younger (18 to 24 year olds)	20	20	40
Middle (32 to 47 year olds)	20	20	40
Older (55 to 65 year olds)	20	20	40
Senior (70 year olds or more)	20	20	40
Total	**80**	**80**	**160**

As Table 2.1 shows, there were 40 participants in each of four age groups—younger (18 to 24 year olds), middle age (32 to 47 year olds), older (55 to 65 year olds), and seniors (70 years old or more). There were 20 males and 20 females within each age group. All 160 participants were licensed drivers. The four age groups included drivers from the metro and non-metro regions and each was paid $50 for his or her participation.

2.1.2 Driving Simulator

In the driving simulation portion of this study, we used a fully interactive PC-based STISIM driving simulator with an automative-style seat that faced a bank of three 21" monitors. Three PCs generated the virtual environment presented on the monitors.

2.1.2.1 Visuals

In this study, the virtual environment shown on the three monitors was a two-lane rural highway. The center display showed the highway ahead while the left and right monitors displayed the countryside beside the highway. A small section in the upper right corner of this display provided a rear view of the participant's route. Also, the lower part of the center display showed the front of the simulated vehicle. Two dials were also shown—one to the left showing driving speed, the other to the right showing the

RPM rate. On the monitors to the left and right, two small sections simulated side-view mirrors that also provided rear views of the route.

2.1.2.2 Sound

Two small speakers located on each side of the monitors generated the simulator's engine noise. The speakers were approximately at the shoulder height of the participants. A subwoofer positioned on the floor beneath the driver's seat provided low-frequency sound.

2.1.2.3 Controls

Each participant controlled the simulator with a steering wheel, an accelerator pedal, and a brake pedal. The simulator PCs registered inputs to these controls and adjusted speed and direction accordingly. The steering wheel was linked to a torque motor, which provided forced-feedback, in order to add realism to the "feel" of the steering.

2.1.2.4 Scenario Development

The driving scenario used in this study was developed using STISIM's Scenario Definition Language (SDL). Additional modifications were made to the experimental scenario so that when drivers crossed the rumble strips, the effect was felt in the steering wheel.

2.1.3 **Experimental Design**

2.1.3.1 Procedure

Prior to the experiment, potential participants were contacted by phone. They were asked their age and whether or not they drove a car. They were recruited if they were in one of the four age groups, currently drove a vehicle, and (1) had not experienced motion sickness in automobiles or in airplanes, (2) had not been sick on any amusement park rides, (3) had not felt queasy at IMAX presentations, and (4) had not had migraines or severe tension headaches.

When each participant arrived at the lab housing the driving simulator, the experimenter examined his or her driver's license to ensure it was valid and to verify the participant's age. Then, the participant read and signed the consent form. The participant was told that he or she would drive in the simulator and then would be asked to complete a brief survey. They were told that the session would be approximately one hour long.

A brief training session followed. In the training session, the participant drove on a simulated six-lane divided highway for approximately six or seven minutes. During the session, which began with the simulator vehicle in the center lane, the participant was asked to accelerate, to reduce speed, and to change lanes. The session continued until the participant felt comfortable driving the simulator vehicle. Then, the experimenter answered any questions that the participant had.

Before each experimental trial the participants were told that they would be driving on a two-lane bidirectional highway. They were asked to "Please drive as you normally would if you were driving on an actual roadway."

To control for possible effects of stimuli presentation order, the 160 participants were randomly assigned to a counterbalanced driving order of the three conditions.

After driving the three drives, the participants left the simulator and moved to a table in the lab. There, they were asked to complete a brief survey. After completing the survey, the participant was debriefed. The debriefing was as follows:

> *"In this study, we're interested in driving behavior in various roadway environments. We'd like you to keep the information about this study confidential. Please do not discuss the study with anyone. We don't want anyone who might take part in the study to know anything about it beforehand."*

After the debriefing, the participant was paid $50. The experimental session lasted approximately one hour.

2.1.3.2 Conditions

Participants drove 10 miles on a two-lane bidirectional highway before they encountered the first warning sign in each of the three drives (conditions). The layout of the control condition is shown in Figure 2.1. The layout of the work zone area and the distance between the warning signs was the same for each of the three conditions; however, the type or content of the warning signs was changed.

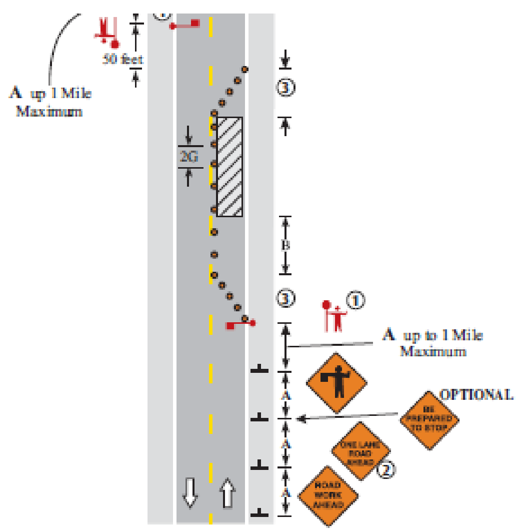

Figure 2.1 Layout of work zone area control condition

In the second condition, the participant encountered four sets of warning signs before they approached the work zone, with the (1) "ONE LANE ROAD AHEAD", (2) combined warning signs of "Flagger Ahead" figure and 45-mile speed limit, (3) combined warning signs of 45-mile speed limit and a dynamic speed limit trailer which indicated the driving speed of the car within a zone (ahead of the trailer, and (4) “BE PREPARED TO STOP” situated 50 feet before portable rumble strips.

In the third condition, flashing LED lights were added to the perimeter of the “ONE LANE ROAD AHEAD” sign and an auditory warning horn sounded when participants exceeded the 45 mph speed limit on their approach to the dynamic speed limit sign.

2.2 RESULTS OF DRIVING SIMULATION EXPERIMENT

2.2.1 Driving Speed Data

2.2.1.1 Analysis of Driving Speed

The driving speed of each participant was recorded across all three conditions. For data analysis purposes, the average driving speed was obtained for each of five 200-ft segments on the approach to the first warning sign. Also, the distance of 750 feet between warning signs was divided into four segments and the average driving speed for each segment was calculated. Table 2.2 shows the segments over which the driving speed was averaged on the approach to the four warning signs and the flagger.

Table 2.2 Segments over which the driving speed was averaged on the approach to the four warning signs and the flagger.

Segment	Distance from the 1st warning sign (in feet)	Distance from the 2nd, the 3rd, the 4th warning sign and the flagger (in feet)
Segment #1	1000 feet to 800 feet	750 feet to 550 feet
Segment #2	800 feet to 600 feet	550 feet to 350 feet
Segment #3	600 feet to 400 feet	350 feet to 150 feet
Segment #4	400 feet to 200 feet	150 feet to 0 feet
Segment #5	200 feet to 0 feet	N/A

Five 4 (age group) x 2 (gender) x 3 (condition) x 5/4 (segment) x 3 (drive) ANOVAs (analysis of variance) were performed to determine the presence of statistically significant differences in average driving speed as the participants approached the four warning signs and the flagger. The contributing factors being considered were as follows:

- Participant age
- Participant gender
- Condition
- Road segment

A summary of the P-values of the five ANOVAs is shown in Table 2.3.

Table 2.3 P-values obtained in the five ANOVAs performed on average driving speed on the approach to the four warning signs and the flagger.

Source of Variance	1st warning sign	2nd warning sign	3rd warning sign	4th warning sign	Flagger
Age	**< 2.2e-16**	**< 2.2e-16**	**< 2.2e-16**	**< 2.2e-16**	**< 2.2e-16**
Gender	**5.608e-08**	**1.426e-09**	**3.130e-06**	**1.057e-07**	**4.648e-09**
Condition	0.4728223	**6.787e-09**	**< 2.2e-16**	**1.859e-10**	**0.0022030**
Segment	**< 2.2e-16**	**< 2.2e-16**	**1.507e-08**	**< 2.2e-16**	**< 2.2e-16**
Age x Gender	**1.001e-08**	**0.003408**	0.150829	0.4166	**0.0005186**
Age x Condition	**0.0003885**	**0.003467**	**0.006036**	**< 2.2e-16**	**0.0005446**
Gender x Condition	0.0971416	0.788686	0.699806	0.7372	0.2238107
Age x Segment	**5.292e-06**	0.997270	0.991880	0.6140	0.6652984
Gender x Segment	0.5539517	0.995360	0.847165	0.3454	**0.0337997**
Condition x Segment	0.9948903	0.063790	0.971395	0.5382	0.1149978
Age x Gender x Condition	0.4384607	0.348821	**0.015695**	0.2123	0.2561880
Age x Gender x Segment	0.4365815	0.999964	0.999825	0.9955	0.9766819
Age x Condition x Segment	0.9733741	1.000000	0.998279	0.9985	0.7639105
Gender x Condition x Segment	0.9832543	0.992581	0.998445	0.9574	0.6808456
Age x Gender x Condition x Segment	1.0000000	1.000000	1.000000	1.0000	0.9999906

Table 2.3 indicates that all the four independent variables affected the average driving speed on the approach to at least one of the warning signs. The significant main effects were presented as:

- *Age:* The average driving speed on all four warning signs and the flagger differed significantly across different age groups of the participants.
- *Gender:* The gender of the participants affected the average driving speed on the approach to all four warnings signs and the flagger.
- *Condition:* Average driving speed differed significantly across the three conditions on approach to all work zone operations, *except* for the first warning sign.
- *Segment*: Highway segment had a significant main effect on the driving speed on approach to all four warning signs and the flagger.

Significant interaction effects can also been found from Table 2.3. Although statistically significant, the magnitude of the average speed differences associated with the interactions was relatively small compared to the main effects. A detailed presentation of the interactions is shown in Appendix A.

To identify the most effective work zone operation, the average speed of the approach to the warning signs and the flagger is presented as a function of the experimental condition. Moreover, analysis was conducted on the effectiveness of the warning horn for participants who drove beyond the speed limit in both of the LED/horn condition and Non-LED/horn condition. Then, we also examined the differences of the average driving speed on approach to the warning signs and the flagger depending on other variables.

2.2.1.2 Effect of test condition on average speed

For all test conditions, the average speed steadily decreased on the approach to the work zone. Table 2.4 presents the mean speeds and standard deviations on the approach to the four warning signs and the flagger.

Table 2.4 Mean speed and standard deviation on the approach to the four warning signs and the flagger as a function of the driving condition

Condition		1st warning sign	2nd warning sign	3rd warning sign	4th warning sign	Flagger
Control	Mean	54.05843	48.82124	45.29008	39.16753	25.92176
	SD	5.473355	8.543835	9.786667	11.239090	11.843617
Non-LED/non-horn	Mean	53.86654	47.14748	40.51633	36.57409	24.25252
	SD	7.357606	9.441902	7.244037	7.913581	9.572261
LED/horn	Mean	54.21466	46.14019	39.84509	36.59886	24.89481
	SD	6.808028	9.436237	6.778814	7.682581	9.246941

Figure 2.2 illustrates the effect of the test condition on the average speed. To further explore the speed differences, Tukey HSD tests applied *post hoc* to the mean speed data revealed no statistically significant differences in mean speeds between the conditions on the approach to the first warning sign, indicating that the LED lights did not contribute to reduced driving speed.

However, statistically significant lower mean speeds were seen within both the non-LED/non-horn and LED/horn conditions (but not in the control condition), *on the approach* to the last three warning signs; there was no difference, however, between the mean speed of the non-LED/non-horn and the LED/horn conditions. When approaching the flagger, only the speed difference between the Non-LED/non horn condition and the control condition was found to be significant.

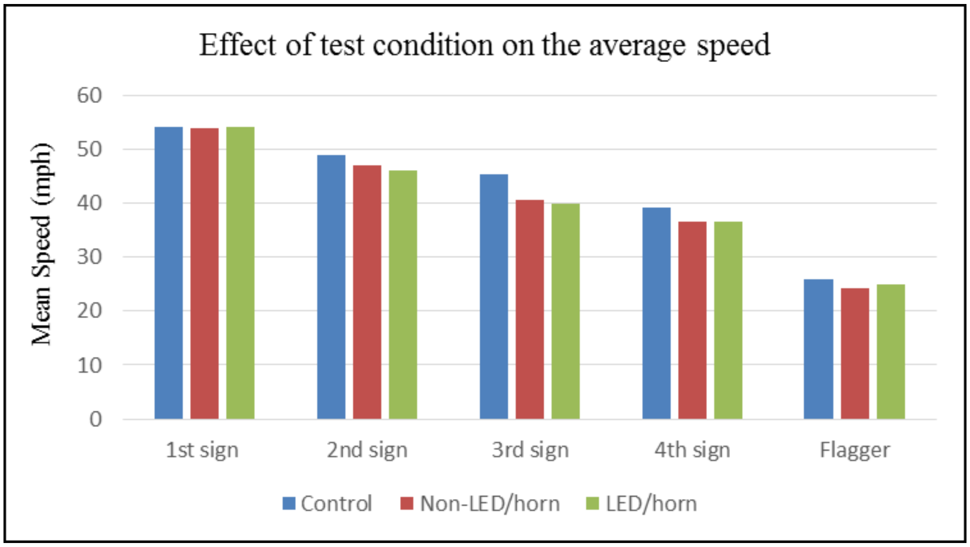

Figure 2.2 Effect of condition on the average speed

2.2.1.3 Analysis of the effectiveness of LED flashing lights

To examine the LED effect, we compared driving speeds when drivers encountered the Non-LED sign and the LED sign. The distance before and after the 1st warning sign was divided into four segments in both of the Non-LED and LED conditions. Segment 1 is 0-200ft *before* the 1st warning sign, while Segment 2 (0-200ft), Segment 3 (200-400ft) and Segment 4 (400-600ft) are *after* the first warning sign. Four one-way ANOVAs were conducted to test whether the average speed of each segment differed significantly across these two conditions. The F-statistics and p-values are shown in Table 2.5.

Table 2.5 The F-statistics and p-values of the LED effect on the average speed over each segment

Segments	F-statistics	P-values
Segment 1	0.047	0.829
Segment 2	0.251	0.617
Segment 3	1.109	0.293
Segment 4	0.791	0.374

Table 2.5 shows that no statistically significant differences were found between the LED and non-LED drives for the four roadway segments. The average speed on the approach to and after the LED and Non-LED signs are presented in Figure 2.3.

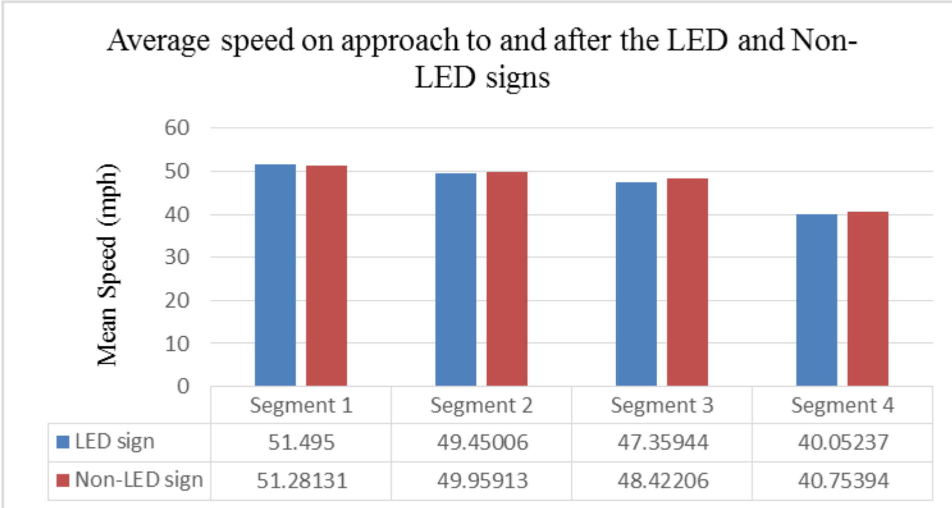

Figure 2.3 Average speed on approach to and after the LED and Non-LED signs

2.2.1.4 Analysis of the effectiveness of the horn

The trigger region of the auditory warning horn was 150 feet before the dynamic speed limit sign for those drivers exceeding 45 mph. The eighteen drivers in the LED/horn condition who exceeded 45 mph in the zone of the dynamic speed limit sign experienced the auditory warning horn.

For purposes of comparison we also extracted the driving speed data for the 19 participants who exceeded the 45 mph speed limit in the equivalent zone of the dynamic speed limit sign in the non-horn condition.

To examine how the horn affected speed reduction, the roadway surrounding the dynamic speed limit sign was divided into 4 segments. Segment 1 is 0-150ft *before* the dynamic speed limit sign, while Segment 2 (0-200ft), Segment 3 (200-400ft) and Segment 4 (400-600ft) are *after* the dynamic speed limit sign. The speed of those who heard the horn in the LED/horn condition and those who exceeded the 45 mph speed limit in the non-horn condition was averaged over each segment. A one-way ANOVA was conducted for each segment to examine the effect of the horn on average driving speed. The F-statistics and P-values are presented in Table 2.6.

Table 2.6 The F-statistics and p-values of the horn effect on average speed for each segment

Segments	F-statistics	P-values
Segment 1	3.422	0.0728
Segment 2	4.301	0.0455
Segment 3	4.4	0.0432
Segment 4	1.552	0.221

Table 2.6 shows that driving speeds did not differ significantly for the horn vs non-horn condition on the approach to the dynamic speed limit sign. However, after the drivers heard the horn, their speed was reduced significantly in Segment 2 and Segment 3. By Segment 4, however, no statistically significant difference is present between driver speed for drivers in the horn condition and the non-horn condition. See Figure 2.4 for a segment-by-segment breakdown of mean driving speeds as a function of the horn versus non-horn conditions. Based on these findings we can conclude that there is a statistically significant effect of the warning horn on the speed reduction after the dynamic speed limit sign. However, the horn did not have a continued, pronounced effect going into the work zone. It is important to remember that the horn is intended to capture the attention of driver outliers in work zones. The results of this analysis reveal that the horn did capture the attention of outlier drivers and led to statistically significant reductions in driving speed in comparison to those driver outliers who did not hear the horn.

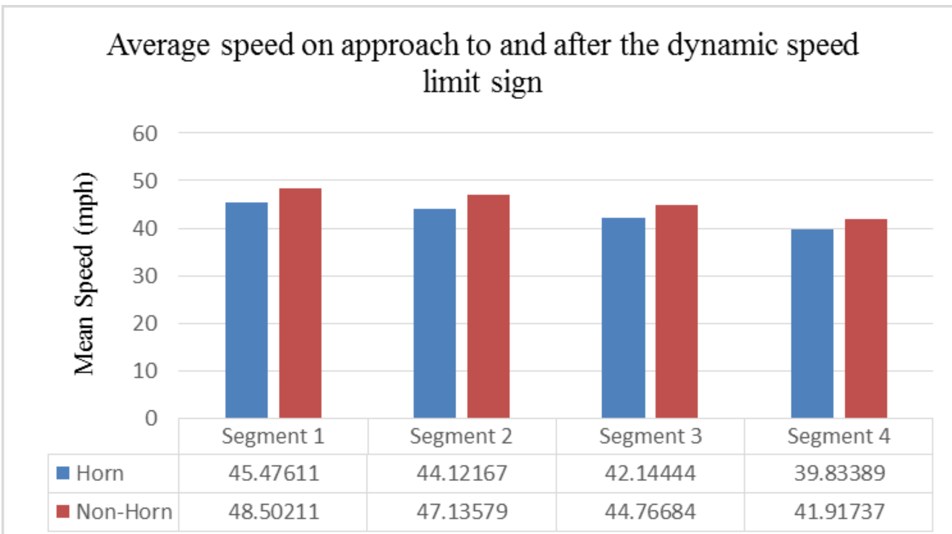

Figure 2.4 Mean speed on the approach before and after the dynamic speed limit sign in horn and non-horn conditions

2.2.1.5 The effect of in-lane transverse rumble strips on driver behavior

To investigate the effect of the rumble strips on driver behavior, the lateral lane position of the car was recorded in both the Non-LED/non-horn and LED/horn conditions. The results indicate that nine participants left their lane to avoid experiencing the rumble strips for at least one of the conditions. Of the nine, three participants left their lane to avoid the rumble strips in both conditions, while the other six left the lane to avoid the rumble strips only once.

Of those who avoided the rumble strips two were from the Younger group (18 to 24 years), five were from the Middle group (32 to 47 years), and two were from Older group (55 to 65 years). No Senior participants (70+ years) changed lanes to avoid the rumble strips. With respect to gender, seven females avoided the rumble strips while only two males did.

Please note: It is not dangerous for drivers to leave their lane in a flagger-controlled work zone because the opposing lane is closed to oncoming traffic. The intent of this research is to generate driving contexts that capture driver attention. The data show that rumble strips facilitate this intent.

2.2.1.6 Effect of age group on average speed

Table 2.7 indicates the differences in average speed for each age group as drivers approach the four warning signs and the flagger. For all age groups, participants reduced their driving speed as they approached the work zone.

Table 2.7 Average speed on approach to the warning signs and the flagger as a function of the age of the participants

Age group		1st warning sign	2nd warning sign	3rd warning sign	4th warning sign	Flagger
Younger (18 to 24 years old)	Mean	57.15425	52.30850	46.20465	41.87521	29.97058
	SD	5.574729	5.766327	6.573058	7.263411	10.519595
Middle Age (32 to 47 years old)	Mean	56.10735	51.07292	45.48171	40.31252	27.52652
	SD	4.046072	6.907403	7.334728	8.356977	9.962879
Older (55 to 65 years old)	Mean	52.44587	44.75090	39.37346	34.46185	21.30756
	SD	6.549610	9.130760	7.707065	9.184613	8.983437
Senior (70+ years old)	Mean	50.40637	41.26906	36.37229	33.05512	21.28515
	SD	7.384437	9.653939	7.589879	8.553223	8.663483

Figure 2.5 presents mean speed as a function of participant age group. Generally, the mean driving speed was higher for the younger age groups than the older age groups.

The results of the Tukey HSD tests indicate that the average speeds of the four age groups were significantly different from each other on the approach to the first and the fourth warning signs. However, when participants approached the second and the third warning signs, there were no statistically significant speed differences between the Younger and the Middle Age groups. The two younger age groups drove at significantly higher speeds, on average, than the Older and the Senior groups. It was also indicated that the Older and Senior participants did not differ significantly on their approach to the flagger.

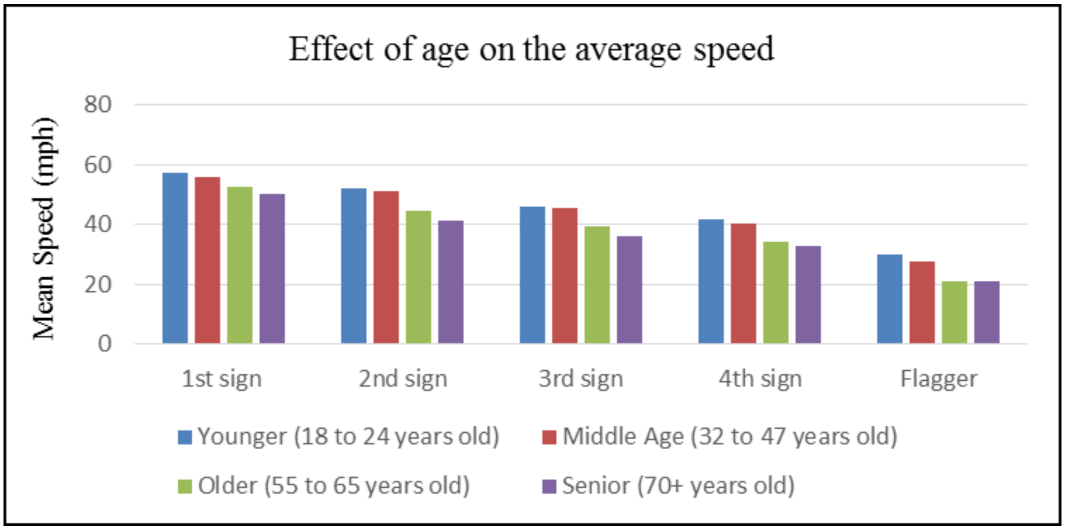

Figure 2.5 Effect of age on the average speed

2.2.1.7 Effect of gender on average speed

Table 2.8 presents the means and standard deviations of driving speed as a function of gender and roadway elements. For both males and females, the average speed decreased from the first warning sign to the flagger.

Table 2.8 Average speed on approach to the warning signs and the flagger as a function of the gender

Gender		1st warning sign	2nd warning sign	3rd warning sign	4th warning sign	Flagger
Female	Mean	53.38567	46.27796	41.11780	36.46930	23.90211
	SD	6.516387	9.811168	9.069157	9.566229	10.17433
Male	Mean	54.67125	48.42273	42.59825	38.38305	26.14279
	SD	6.630059	8.438196	7.597822	8.637237	10.29128

Figure 2.6 presents the effect of gender on mean speed. Males drove at a higher speed on average than females.

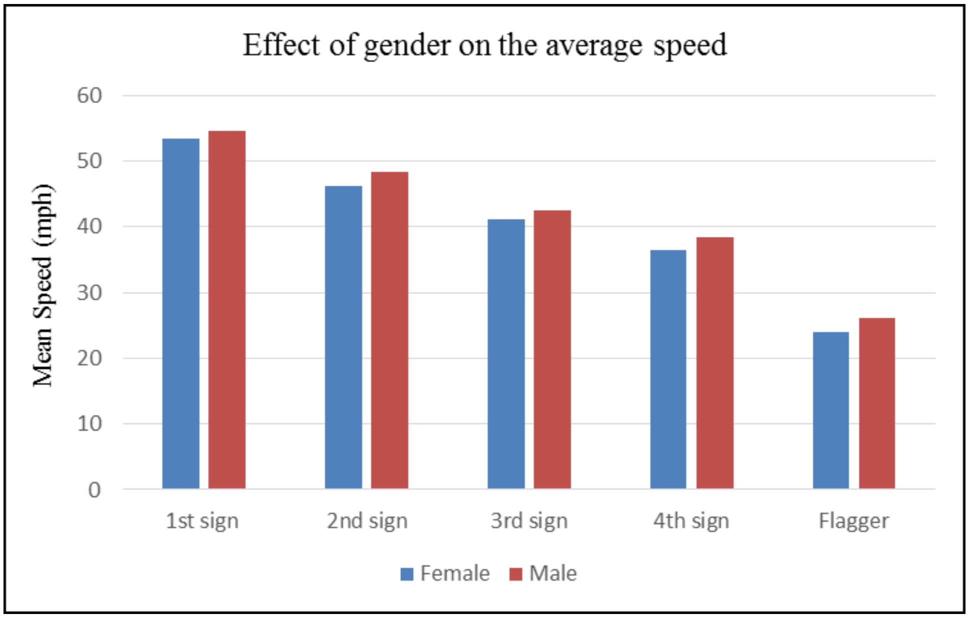

Figure 2.6 Effect of gender on the average speed

2.2.1.8 Effect of highway segment on mean speed

Table 2.9 shows the mean driving speeds on the approach to the warning signs and the flagger as a function of highway segment. Overall, mean speeds declined on the approach to the warning signs. Highway segment significantly affected mean speed.

Table 2.9 Average speed on approach to the warning signs and the flagger as a function of the highway segment

Segment		1st warning sign	2nd warning sign	3rd warning sign	4th warning sign	Flagger
Segment #1	Mean	56.28256	49.94267	43.32742	40.26321	30.72840
	SD	4.857326	8.606393	8.724663	7.833072	10.162260
Segment #2	Mean	55.33394	48.29694	42.16729	38.96042	27.47004
	SD	5.115247	8.801291	8.334924	7.989661	9.330731
Segment #3	Mean	54.09908	46.45977	41.18973	36.56262	22.08687
	SD	6.007801	9.296837	8.324175	9.081719	9.144631
Segment #4	Mean	52.89773	44.70200	40.74767	33.91846	19.80450
	SD	7.065297	9.298627	7.975993	10.250627	8.707271
Segment #5	Mean	51.52898	N/A	N/A	N/A	N/A
	SD	8.262915	N/A	N/A	N/A	N/A

The driving speed trajectories of each segment on approach to the warning signs and the flagger are presented in Appendix B. The figures reveal that the mean speeds consistently declined on the approach to the work zone.

2.3 SURVEY DATA

After completing the three drives, the 160 participants were asked to respond to six survey questions pertaining to, for example, the extent to which they demonstrate consideration for other drivers, pedestrians, and bicyclists. The participants were also queried about awareness of road conditions while driving and whether they text while driving. Though the survey was not the focal point of our research, and thus an extensive statistical analysis was not performed, the survey questions and descriptive statistics are presented in Appendix C.

2.4 SUMMARY FINDINGS

In this exeriment, we used a driving simulator to identify elements that capture and sustain driver attention in flagger-controlled work zones. We obtained lane position data and driving speed data from the 160 participants who drove the simulated rural highway three times. We were particularly interested in determining whether flashing LED lights mounted on the first warning sign of an approach to a flagger-controlled work zone contributed to more significant reductions in speed than the same sign without the flashing LED lights. We are also particularly interested in whether a horn blast emitted for drivers exceeding 45 mph on their approach to an intelligent speed limit display effectively captured the attention of outlier drivers. And we were interested in determining the effectiveness of transverse rumble strips as an attention-grabbing device in a simulated flagger-controlled work zone.

Our main findings are the following:

- The new set of elements is more effective than the elements currently used to reduce driving speeds on the approach to the flagger-controlled work zone;
- We found no difference in mean driver speed in response to the sign with an LED presence;
- The dynamic speed display coupled with the horn is more effective than the dynamic speed display alone;
- Survey responses provide helpful self-reported information from drivers.

CHAPTER 3: FIELD STUDY

Method and Findings
John Hourdos, PhD
University of Minnesota

3.1 INTRODUCTION

The second pilot test of the attention getting devices in an active work zone was conducted in Spring Valley, MN on CSAH 8. The work zone was being managed by Rochester Sand and Gravel who were performing a full depth reclamation and resurfacing of 4.1 miles of CSAH 8 north of Spring Valley. The team was deployed from 10/8/15 – 10/17/15 and collected data on 8 days within that time period. During that time, the research team setup and deployed two different work zone layouts alongside the active work zone on one approach. The first, referred to as base, was the minimum standard setup following Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) guidelines. This setup was supplemented with additional radar sensors, manufactured by Smartmicro, to gather data from the approaching vehicles during the base conditions. The second setup deployed, referred to as the experimental in this report, included additional signs and attention getting devices (Horn, Rumble Strips, Speed Trailer). This layout was also instrumented with additional radar sensors and cameras to gather data on the approaching vehicles.

The first field test of the new proposed work zone layout in an active work zone was conducted in Pine City, MN on State Highway 70. The work zone was active over the course of 4 days ranging from 10/06/2014 – 10/09/2014. Unfortunately, a combination of short work zone working periods as well as low traffic volumes did not allow for the collection of a statistically secure sample of speeds. Even so, the results from the two tests are very comparable, a fact that reinforces the observations collected and conclusions reached since the two sites were very far from each other, on a different time period, and operated by completely different work zone crews.

In summary, we observed that the combination Speed Trailer and Horn Barrel succeeded in reducing the overall speed of vehicles approaching the work zone. In contrast, the portable rumble strips did not generate any significant speed reduction.

3.2 BASE DEPLOYMENT

The base setup consisted of signs laid out according to the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD). The only additions made to the setup were the data collection sensors hidden behind each sign, which include 5 radar sensors and 4 HD cameras. Due to the activity of the work zone the locations of the equipment changed daily, however the layout and distance between stations remained the same.

3.2.1 Layout

Figure 3.1, below, presents a diagram of the work zone on a typical day (not to scale) and the relative positions of each station during a base deployment.

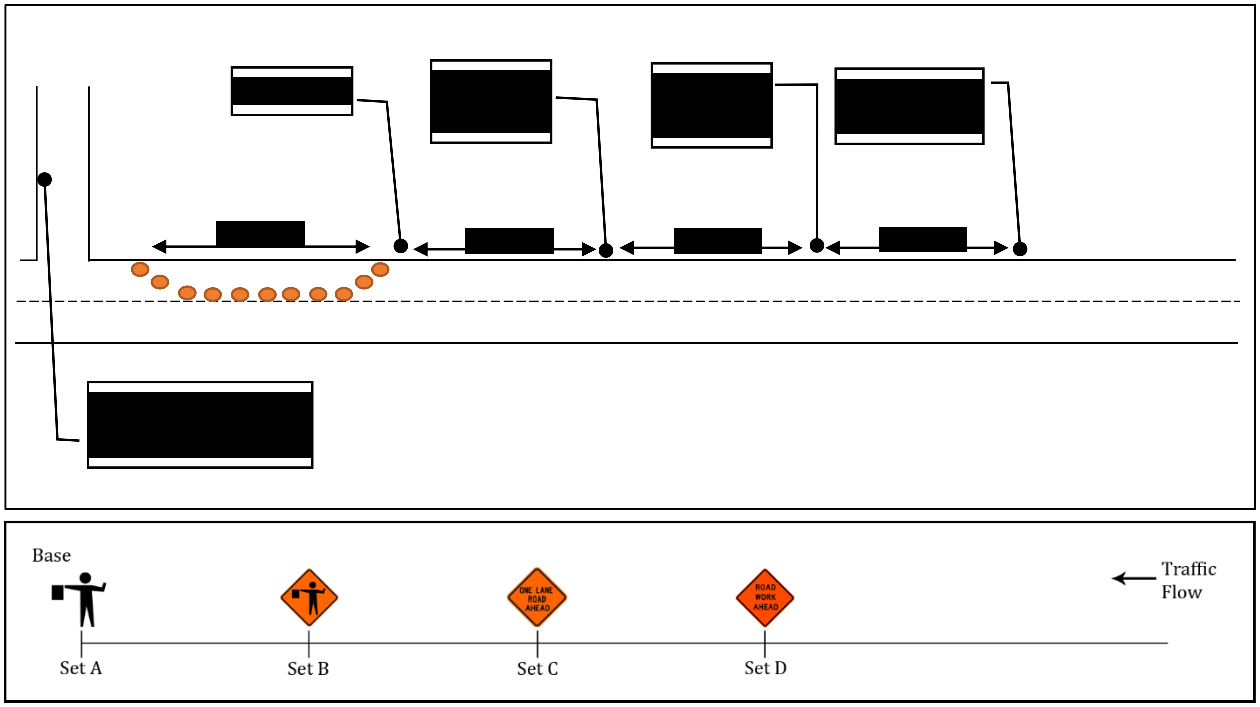

Figure 3.1 Base deployment layout (not to scale)

3.2.2 Flagger Location (1)

This location, seen in Figure 3.2, included a type 29 radar and a radio mounted on a 10 ft square aluminum pole, secured to a standard dual spring sign holder at the edge of the road 100ft behind the flagger. An HD camera was also added and looked away from the work zone. A single pelican weather proof box held the batteries, communication equipment, and backup recording devices.

Figure 3.2 Base deployment flagger location field picture

3.2.3 Flagger Icon Sign (2)

This location, seen in the background of figure 3.3, included a type 32 radar and a radio on a 10ft square aluminum pole, secured to a standard dual spring sign holder at the edge of the road behind the portable sign. A single pelican weather proof box held the batteries, communication equipment, and backup recording devices.

3.2.4 One Lane Road Ahead (3)

This location, seen in the middle of figure 3.3, included a type 32 radar and a radio on a 10 ft square aluminum pole, secured to a standard dual spring sign holder at the edge of the road behind the portable sign. Two HD cameras were also added and looked both into and away from the work zone. A single pelican weather proof box held the batteries, communication equipment, and backup recording devices.

3.2.5 Road Work Ahead (4)

This location, seen in the foreground of figure 3.3, included two type 30 radars and a radio mounted on a 10 ft square aluminum pole, secured to a standard dual spring sign holder at the edge of the road behind the portable sign. One radar was pointed away from the work zone at approaching vehicles. The other radar was pointed backwards into the work zone and tracked the vehicles after they passed the Road Work Ahead sign. An HD camera was also added and looked into the work zone as vehicles passed the sign. A single pelican weather proof box held the batteries, communication equipment, and backup recording devices.

Figure 3.3 Base deployment entire approach field picture

3.3 EXPERIMENTAL DEPLOYMENT

The experimental deployment setup used signs found in the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD). In addition, alternative attention getting devices were deployed including portable rumple strip, a speed trailer (with a 45mph construction zone speed limit displayed), and a custom barrel horn designed by the Minnesota Traffic Observatory that alerts the driver via audio ques when speeding next to the device. To collect information on vehicles in the work zone data collection sensors were hidden behind each sign, which include 5 radar sensors and 4 HD cameras. Due to the activity of the work zone the locations of the equipment changed daily, however the layout and distance between stations remained the same.

3.3.1 Layout

Figure 3.4, below, shows a diagram of the work zone on a typical day (not to scale) and the relative positions of each station during an experimental deployment.

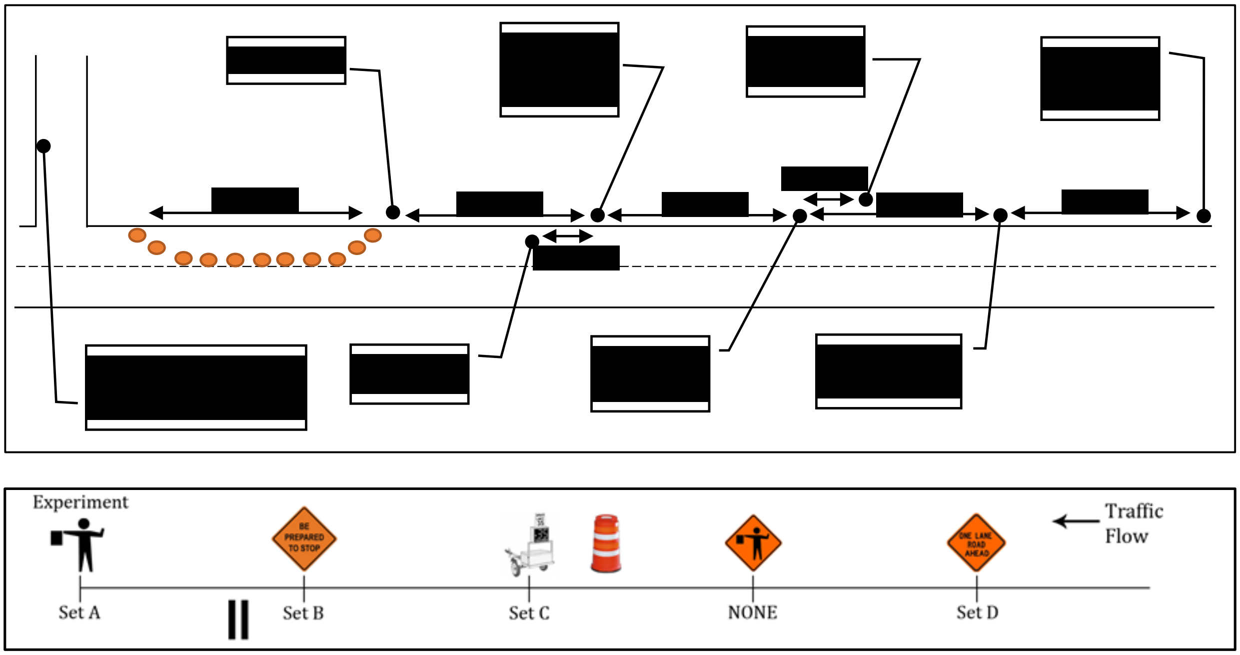

Figure 3.4 Full deployment layout (not to scale)

3.3.2 Flagger (1)

Figure 3.5 shows a field photo of the full deployment flagger location. This location included a type 29 radar and a radio mounted on a 10 ft square aluminum pole, secured to a standard dual spring sign holder at the edge of the road 100 ft behind the flagger. An HD camera was also added and looked at away from the work zone. A single pelican weather proof box held the batteries, communication equipment, and backup recording devices.

Figure 3.5 Full deployment flagger location field picture

3.3.3 Rumble Strips (2)

Figure 3.6 is a photo of the portable rumble strips. This location is 50 ft downstream from the "Be Prepared to Stop" sign. No other equipment was deployed at this location.

Figure 3.6 Full deployment rumble strip location field picture

3.3.4 Be Prepared to Stop (3)

Figure 3.7 shows the "Be Prepared to Stop" sign. This location included a type 32 radar and a radio on a 10 ft square aluminum pole, secured to a standard dual spring sign holder at the edge of the road behind the portable sign. A single pelican weather proof box held the batteries, communication equipment, and backup recording devices.

Figure 3.7 Full deployment be prepared to stop sign location field pictures

3.3.5 Speed Trailer (4)

The location presented in Figure 3.8 included a type 32 radar and radio mounted on a 10 ft square aluminum pole, secured to a MnDOT speed trailer at the edge of the road. Two HD camera was also added and looked both into and away from the work zone. A single pelican weather proof box held the batteries, communication equipment, and backup recording devices.

Figure 3.8 Full Deployment Speed Trailer Location field picture

3.3.6 **Barrel Horn (5)**

The location in Figure 3.9 had a standard work zone construction barrel that had been designed by the Minnesota Traffic Observatory and alerts the driver via audio ques when speeding next to the device. If a vehicle approaches the work zone above the speed limit posted on the speed trailer (45mph) the horn would blast for a one second. The signal for the horn to be fired was provided by the type 32 radar attached to the speed trailer.

Figure 3.9 Full deployment barrel horn location field pictures

3.3.7 Flagger Icon Sign (6)

This location did not include any additional sensors and only contained the standard Flagger Icon sign seen in Figure 3.10

Figure 3.10 Full Deployment flagger icon sign location field pictures

3.3.8 One Lane Road Ahead Sign (7)

This location presented in Figure 3.11 included two types of 30 radars' and a radio mounted on a 10 ft square aluminum pole, secured to a standard dual spring sign holder at the edge of the road behind the portable sign. One radar was pointed away from the work zone at approaching vehicles. The other radar was pointed backwards into the work zone and tracked the vehicles after they passed the One Lane Ahead sign. An HD camera was also added and looked into the work zone as vehicles passed the sign. A single pelican weather proof box held the batteries, communication equipment, and backup recording devices.

Figure 3.11 Full Deployment one lane road ahead sign location field pictures

3.4 RADAR DATA COLLECTION AND EXTRACTION

Data collected from the radar is extremely abundant due to the fact that they transmit a data "message" every 1/20th of a second. This data needed to be read and stored in real time during the work zone experiment. After the work zone the data was decoded from its binary message format and specific data from each message was extracted and converted into a common CSV for additional analysis. This chapter outlines the format of the CSV files, the data collected, and the method for extracting the individual vehicle trajectories.

3.5 DATA DESCRIPTION

Each radar sensor produces a "message" every 1/20th of a second (50 milliseconds) while powered. Each of these messages contains all the information about the sensor, its targets, and additional data. Most of this data is not necessary for our analysis but was saved in the raw binary format in case it would be needed later. After data collection was completed the binary data went through post processing and only the data of interest was saved into comma-separated values (CSV) files.

Each CSV file, one for each day, contains a table with a variable number of rows and 8 columns. Each row, as seen in Figure 5.12, represents a single target from a single sensor and therefore multiple rows can have the same timestamp. For example, if a radar sensor sees three targets in its view the CSV file would contain three separate rows with the same time stamp and sensor ID but different target values.

	A	B	C	D	E	F	G	H
1	time	sensor_id	object_id	x	y	vx	vy	length
2	1444329369.396480	3	18	1151.256	-13.568	21.600	-21.600	3.20
3	1444329369.456500	3	18	1149.720	-13.888	21.600	-21.600	4.40
4	1444329369.496010	3	18	1148.568	-14.592	21.600	-21.600	4.40
5	1444329369.546440	3	18	1147.416	-15.168	21.700	-21.700	4.40
6	1444329369.600730	3	18	1146.328	-15.680	21.700	-21.700	4.40
7	1444329370.095360	3	18	1145.304	-15.936	21.700	-21.700	4.40

Figure 3.12 CSV File Format Example

The first column in the CSV file is "time", which is represented as UNIX time (the numbers of seconds since Jan 01 1970 (UTC)). The second column is the "sensor_id", each sensor deployed in the work zone had a unique ID from 0 to 4 (5 total). The third column is the "object_id", which is a unique value given to each target by the radar. These id's range from 0 to 63, and once id 63 is used the radar begins again at id 0. Therefore, in the range of each radar sensor every vehicle tracked will be given a unique id as long as the radar does not lose its target. However, as a vehicle traverses the work zone and enters the range of each sensor, unique targets will be created in each radar sensor and are more often than not given different object ids by each radar sensor. The fourth and fifth columns represent x and y coordinates of each target respectively. These positions are represented, in meters, as the distance away from the recorded position of the flagger. The sixth and seventh columns represent lateral speed and longitudinal speed in meters/second. Finally, the last column represents the radars calculated lengths of vehicles in meters. For the purposes of this study the y coordinate and longitudinal speed were omitted.

3.6 DATA COLLECTED

During the deployment in the active work zone each radar had to be calibrated for the current setup, whether base or experiment, and physical location on each day. This process generally took 30 minutes to an hour. As was mentioned previously the radar produces one "message" ever 1/20th of a second even if there are no vehicles present. Therefore, during post processing and while generating the CSV files, rows containing no targets were thrown out. Even with this reduction in data the entire process still resulted in several hundred thousand points for each day of data collection.

Table 3.1 and Table 3.2 present a summary of the data collected each day after a primary filtering of vehicles moving away from the work zone and all data points with speeds less the 5 mph (2.235m/s). Additional effort was needed to extract full trajectories and isolate individual leader vehicles from the data which is explained in more detail in the following section "4.4 - Data Extraction." Due to the level of effort needed to extract the full trajectories the most ideal days, those collected on pavement, were prioritized. Later, it was decided to not work with the dirt road days because the speeds were already very low. Even before arriving at the work zone.

Table 3.1 Data collected from Experiment deployment

Day	Road Conditions	Potential/Partial Trajectory	Data Points	Data (hours)	Full Trajectories	Leader Vehicles (stop/no stop)
Day 1 – Oct 8	Pavement	166	215620	4.73	*	*
Day 4 – Oct 12	Pavement	117	197429	10.07	95	49 (20/29)
Day 5 – Oct 13	Packed Dirt	146	274487	9.82	*	*
Day 6 – Oct 14	Packed Dirt	138	268617	9.89	*	*
Day 7 – Oct 16	Pavement	133	247791	5.37	71	33 (13/20)

* Data not fully processed

Table 3.2 Data collected from base deployment

Day	Road Conditions	Potential/Partial Trajectory	Data Points	Data (hours)	Full Trajectories	Leader Vehicles (stop/no stop)
Day 2 – Oct 9	Unpacked Dirt	63	143043	4.97	*	*
Day 3 – Oct 10	Pavement	57	92570	2.74	50	36 (12/24)
Day 8 – Oct 17	New Pavement	212	300308	7.70	196	67 (30/37)

* Data not fully processed

3.7 DATA ERRORS

In almost any form of data collection errors are inevitable. Using QGIS (an Open Source Geographic Information System) to plot all the data points, allows the formation of trajectories and aids in the discovery of different types of errors. After observation, data errors are divided into 3 types: data missing, data redundancy, and noise.

3.7.1 Data Missing

Data missing refers to, as the name suggests, when the radar loses a vehicle and does not create target information. This can happen for a variety of reasons but is mostly caused by loss of line of sight with a vehicle, vehicles leaving the approach via a side street, or vehicles that stop moving. Data missing is further divided into four different types as seen in Figure 3.13. Type A, depicts some segments of data points are missing when vehicles are passing through the work zone. Type B, represents vehicles that stop in front of the flagger and the radar cannot detect them due to the fact that the radar is based on the Doppler effect and when vehicles stop moving they become indistinguishable from the background. If a vehicle stops for a very long time it can be difficult to associate the other half of the trajectory since the radar will see them as two separate vehicles and see them as such. Type C, characterizes when a vehicles trajectories disappear at a given point and never shows up again. This may happen when a vehicle exits to a side street or if a large vehicle, such as a semitrailer, blocks the radars line of sight with the vehicle. Type D, symbolizes when a vehicle is not picked up until very late in the work zone. This most likely occurred due to a vehicle entering at some mid-point in the work zone or if a vehicle that has been parked for a long time (5+ minutes) begins moving again.

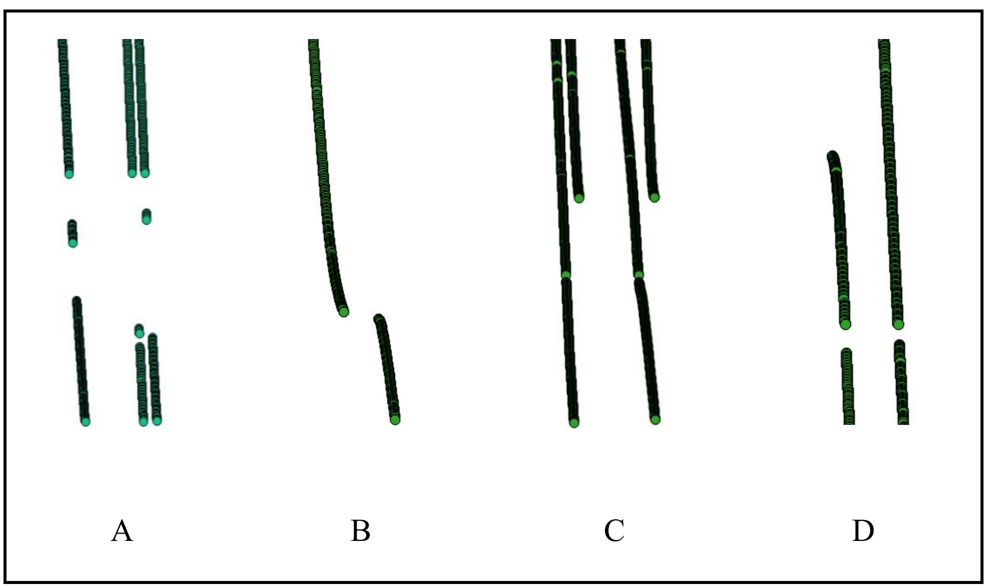

Figure 3.13 Examples of Missing Data

3.7.2 Data Redundancy

The characteristic of data redundancy (exemplified in Figure 3.14) is when two trajectories are so close together that the time difference between them is less than 1 second. Data redundancy is often created when a single vehicle is within the range of two radar sensors at once. Given the field location properties the radar was not able to be calibrated to the precision necessary for the trajectories to be perfectly aligned and results in a slight discrepancy between the two. This could also be caused by two vehicles following very close together, but due to the very short time between vehicles (< 1 sec) it is most likely the former.

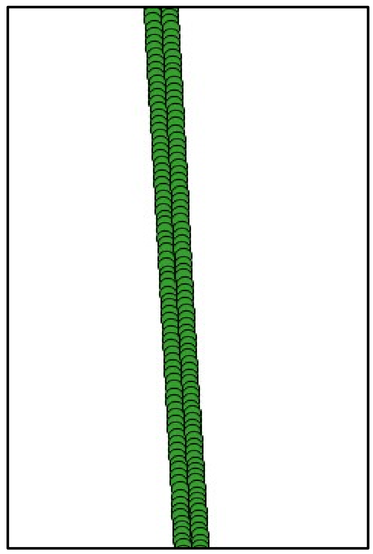

Figure 3.14 Example of redundant data

3.7.3 Noise

The definition of noise (exemplified in Figure 3.15) is when sporadic points or a short segment of trajectories with abnormal slopes are found. Some of this is due to secondary reflections off of highly reflective materials (large metal construction signs) or other objects not on the road such as combines in adjacent fields, animals, the research team, or the work zone crew.

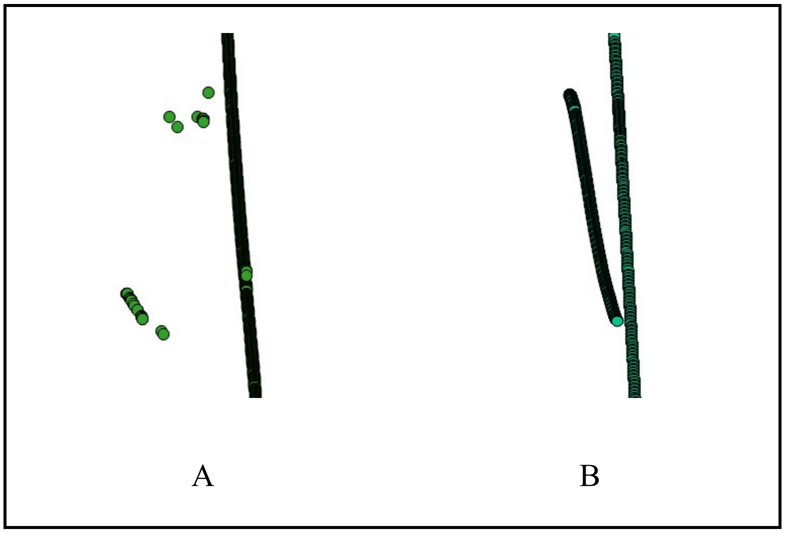

Figure 3.15 Examples of noise

3.8 DATA EXTRACTION

The data extraction process is made up of two steps. In the first step, MATLAB is used to create the markers for the trajectories of leader (first-in-line) vehicles. In the second step, with the assistance of trajectory markers made in MATLAB, trajectories of leader vehicles were selected by hand.

3.8.1 - Markers Creation

In the first step, markers identifying the leader vehicles are created to assist in determining which trajectory to select in the second step. The algorithm used to generate the markers is as follows:

A. Import CSV files and sort each tables by sensor types and UNIX time.
B. Create a window that contains all the data points in a 10-meter range (Figure 5.16) with the target sensor located at the middle of this window. For example, if the headways of vehicles at the position of speed trailer are needed and the X coordinate for speed trailer is 503.8m, then all the data points with X coordinates between 498.8m and 508.8m are collected. All other data points outside this selection are filtered out.

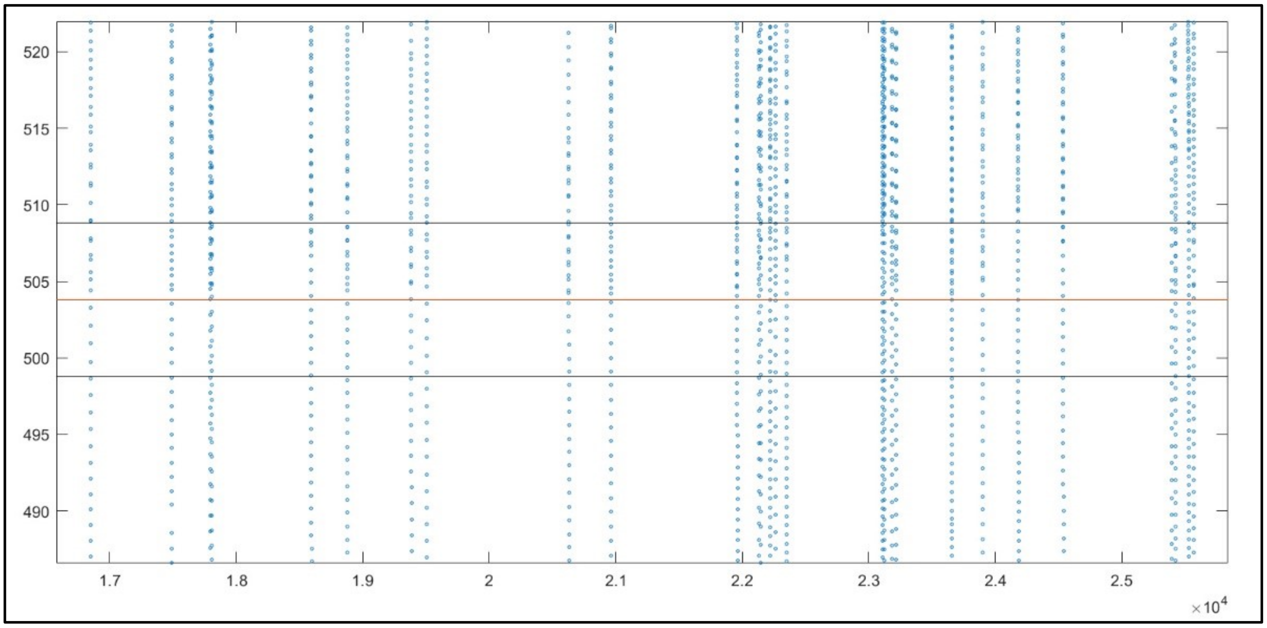

Figure 3.16 Window for data collection

C. All trajectories are saved as thousands of data points in a table, so these points need to be divided into different groups. A headway of 4 seconds is considered as the threshold to distinguish between the minimum amount of time it would take to for a vehicle to traverse the 10-meter segment and the criteria for being separated into individual trajectories. To verify the 4 second headway was an acceptable threshold a test was done in QGIS where time and the X coordinates of all data points were plotted. As seen in Figure 3.17, the trajectory with a smallest slope (i.e. the vehicle that spends the most time passing through the 1-meter segment) fits within the 4 second headway box plotted.

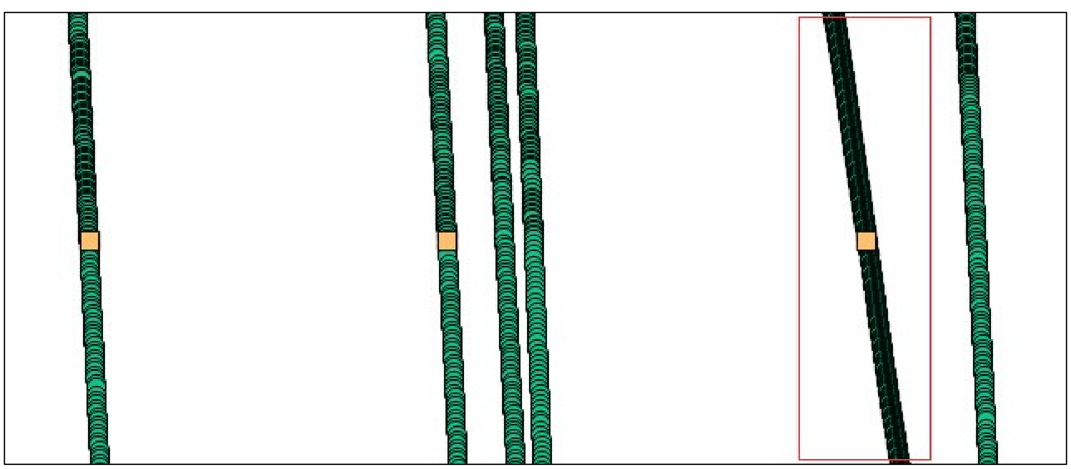

Figure 3.17 Time-headway threshold verification

D. The algorithm then scans through the table from top to bottom, and compares the time differences between row i and the first row. If the time difference is larger than 4 seconds, which means next data point belongs to a different trajectory, then row $i+1$ is regarded as the first row in next group. The same operation is repeated again and again until all the data points are divided into groups. In this way, data redundancy can be removed because if two trajectories are so close that their total time span is smaller than 4 seconds, those trajectories will be regarded as one trajectory.
E. The next step in the algorithm is to plot regression lines for each group and calculate their intersection points with a horizontal line. The Y value of this line is equal to the X coordinate of the location chosen (such as the speed trailer) where the X coordinates for each station varies daily. The X coordinates and time of all intersection points were extracted into a new table and plotted on top of the existing trajectories.
F. A scan of the table created in last step was done and compared the time differences between two adjacent data points. If a difference is larger than 30 seconds, the latter point is assumed to belong to a leader vehicle. The 30 second headway was used as a threshold for defining different platoons of vehicles and the criteria for being labeled a "leader".
G. After creating the markers at the location of interest, the markers near the end of work zone approach (i.e. closest to the flagger) are also created. The latter type of markers checks the headway between vehicles in front of the flagger. Table 5.3 shows these two types of markers created for each day.

Table 3.3 Algorithm Created Markers

File Name	Marker1	Marker2
Oct08	151	138
Oct09	56	44
Oct10	52	46
Oct12	97	80
Oct13	123	125
Oct14	124	124
Oct16	112	71
Oct17	159	127

3.8.2 Manual Trajectory Extraction

In step two, complete trajectories for leader vehicles were extracted from the complete set of data. The requirement, as stated in the algorithm section, is that the headways between a leader vehicle and another vehicle should be larger than 30 seconds throughout the trip (from the first work zone station to the last station). Three examples of complete trajectories that were extracted are shown in Figure 3.18.

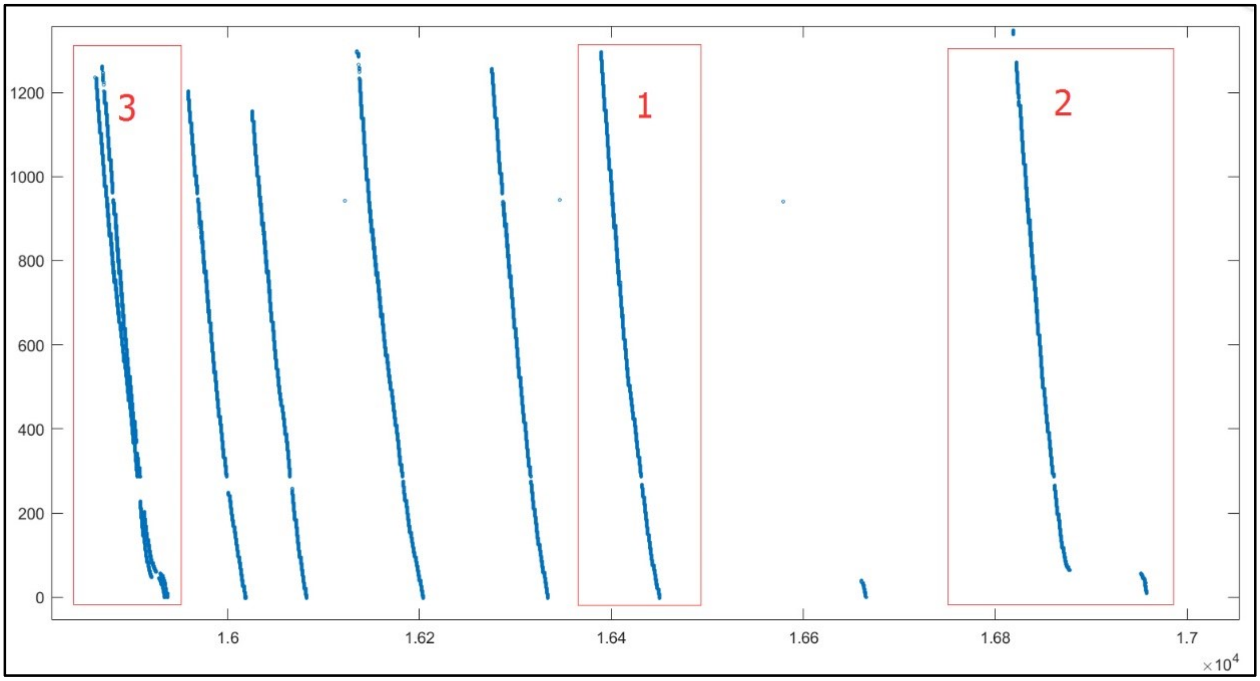

Figure 3.18 Manual trajectory extraction example

Type 1 shows the trajectory of a vehicle that passes the flaggers position without stopping, and the slopes of every segment of this trajectory is always larger than 0. Type 2 illustrates a vehicle that stops in front of the flagger for a moment before being allowed to proceed. Therefore, the entire trajectory is made up with two segments that respectively represent the condition before and after a vehicle stops in front of the flagger. These kinds of trajectories are difficult to extract with simple algorithms because sometimes these two segment are so far apart that the latter portion may be mixed with the trajectories of other vehicles. Type 3 demonstrates two vehicles, following closely, that stop in front of the flagger for a very short time before being allowed to proceed.

The selection of trajectories by hand is the most accurate way to extract the trajectory needed for analysis but is also the most time consuming. A more complex algorithm could be derived but given the relatively small amount of data needed, in terms of the time it would take to code a complex/robust algorithm, it is would be inefficient compared to the manual method. The algorithm described in the previous section is able to help locate the trajectories quicker and helps to accelerate the manual extraction.

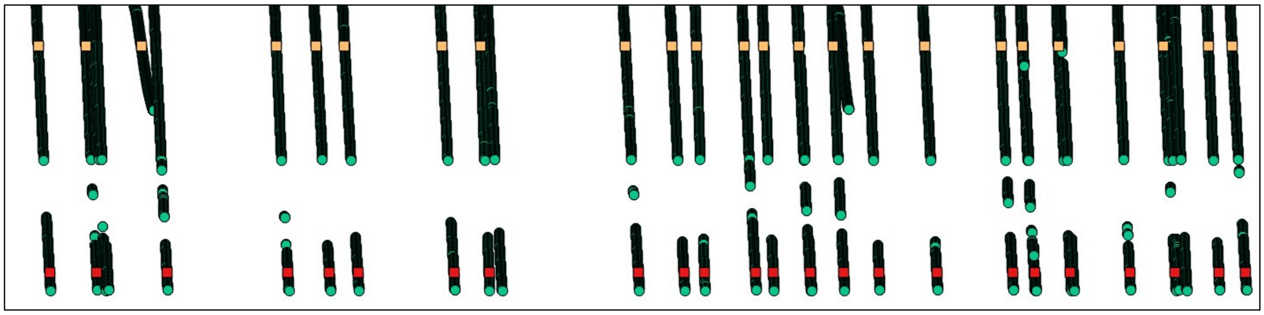

Figure 3.19 Example (Experiment Deployment) of trajectories marked by the algorithm and ready for manual extraction

As Figure 3.19 shows, on an experimental deployment day, orange squares mark those trajectories which meet the 30 second headway requirement when passing the speed trailer. Red squares mark those trajectories which meet the requirement when approaching the flagger. Therefore, if a trajectory is marked by both orange and red squires, it can be regarded as a leader trajectory throughout the trip. Once identified tools in QGIS allow the selection of those points, using polylines, and saving them to a new layer separate from the other data. The final product produces a layer that contains only trajectories that are complete and contain leader vehicles.

3.9 INDIVIDUAL EXAMPLE TRAJECTORIES

Figures 3.20 to 3.23 reveal a preliminary look at the data. These figures depict a single vehicle from one of the 4 main scenarios:

1. Experimental deployment with no stop at flagger
2. Experimental deployment with a stop at flagger
3. Base deployment with no stop at flagger
4. Base deployment with a stop at flagger

The graphs are marked with vertical lines that correspond to location of the radar sensors during the different layouts. The distances marked on the x axis are the number of feet from an arbitrary point upstream to the position of the flagger radar sensor at 4000 ft. The exact position of the flagger is roughly 150 ft upstream of the radar sensor (i.e. 3850 ft).

This work zone was conducted on a road with a low enough volume that many vehicles approaching the work zone did not have to stop for the flagger and instead were allowed to proceed directly into the work zone as directed by the flagger. This represents a distinct change in behavior since as a vehicle approaches the flagger instead of seeing the stop sign they would see the orange slow sign as well as motions from the flagger guiding them to the correct lane. This can be seen in Figure 3.20 and Figure 3.22 where the vehicle never went less then 25mph.

Figure 3.20 shows a vehicle traversing the work zone during an experimental deployment. The vehicle enters the work zone approach at around 60mph and shows a slight decrease in speed as the vehicle approaches the first sign (one lane ahead.) It then maintains a speed around 55mph as it passes the flagger icon sign before decelerating rapidly in around 500ft in front of the speed trailer to a final speed of about 38mph at the speed trailer. After that the vehicle then accelerates up to around 45mph in the first 400ft after the trailer before decelerating again at a fairly constant speed past the “be prepared to stop” sign. The vehicle reaches a final speed of around 25mph as it is passing the flagger.

Figure 3.21 displays a vehicle traversing the work zone during an experimental deployment. The vehicle enters the work zone at around 65mph and decreases at a fairly constant rate for the first 2000ft of the approach and passing the first and second sign settling at a speed of about 58mph. At a distance of around 300ft from the speed trailer the vehicle shows a rapid decrease in speed from 58mph to around 45mph just after the speed trailer. It then maintains a fairly constant deceleration rate while approaching the be prepared to stop arriving at a speed of around 42mph as it passes. The vehicle finally decelerates to a stop from around 40mph to a stop in the final 500ft before the flagger. After a moment the vehicle is released and accelerates into the work zone.

Figure 3.22 illustrates a vehicle traversing the work zone during a base deployment. The vehicle entered the work zone at a speed of around 55mph and continued through the approach with only a slight decrease in speed as it passed the first and second sign. It settled at around 45mph between the one lane road ahead and the flagger icon sign with only a small increase in speed between the two. At around 100 ft in front of the flagger icon sign the vehicle began a deceleration to 35 mph over the next 800 ft until the flagger. At this point the vehicle was given permission to enter the work zone and proceeded through without stopping.

Figure 3.23 depicts a vehicle traversing the work zone during a base deployment. The vehicle entered the work zone with a speed of around 63mph and maintained that speed until the first sign (road work ahead.) At this point it started to decelerate at a fairly constant rate over the next 800 ft and arrived at a speed of about 45mph about 100 ft behind the one lane road sign. The vehicle the accelerated slightly before decelerating again about 300ft in front of the flagger icon sign. About 600 ft in front of the flagger the vehicle began decelerating to a stop from 35 mph. After a moment the vehicle is released and accelerates into the work zone.

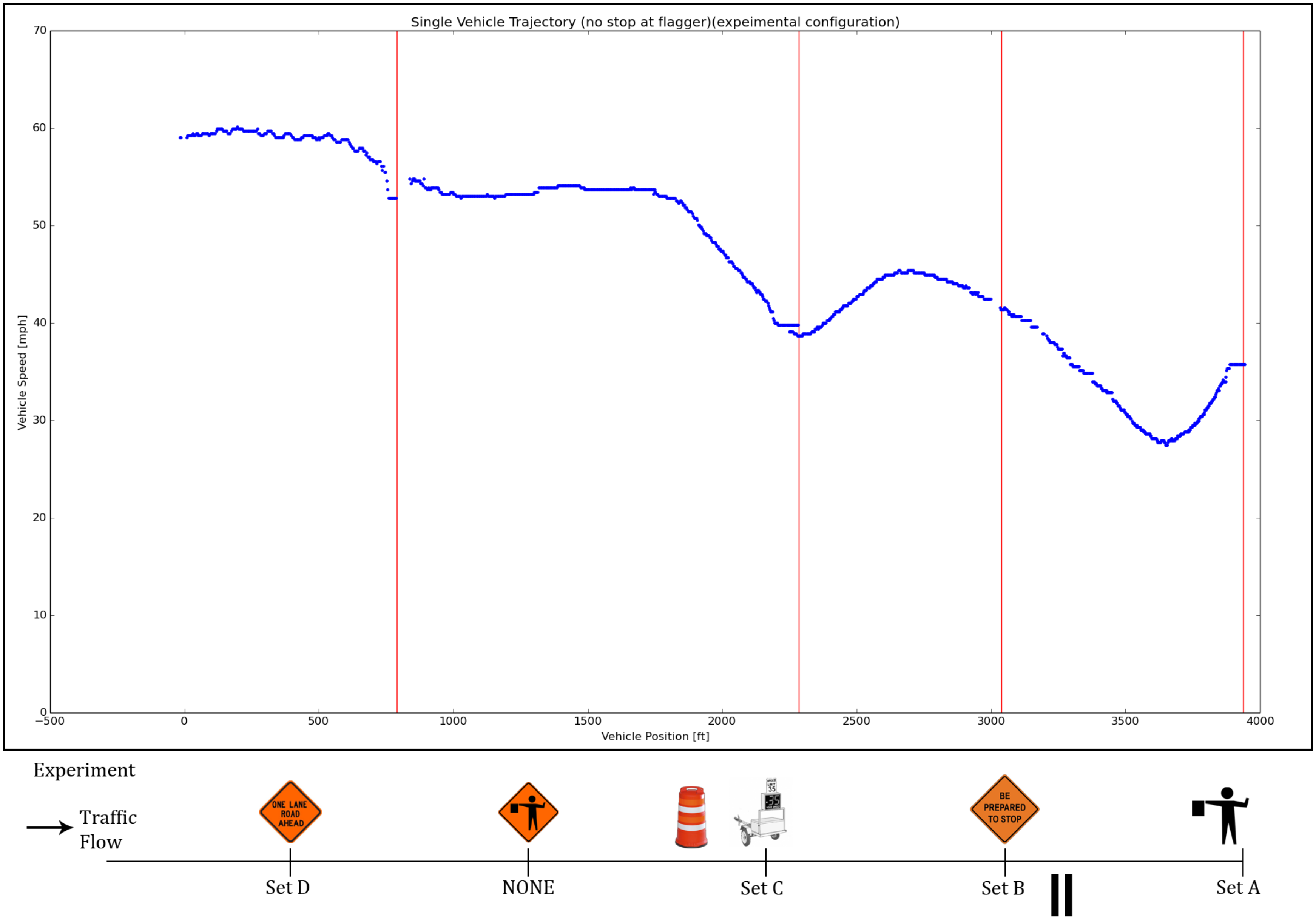

Figure 3.20 Example Trajectory of a Vehicle During the Experimental Layout That Did Not Stop at The Flagger

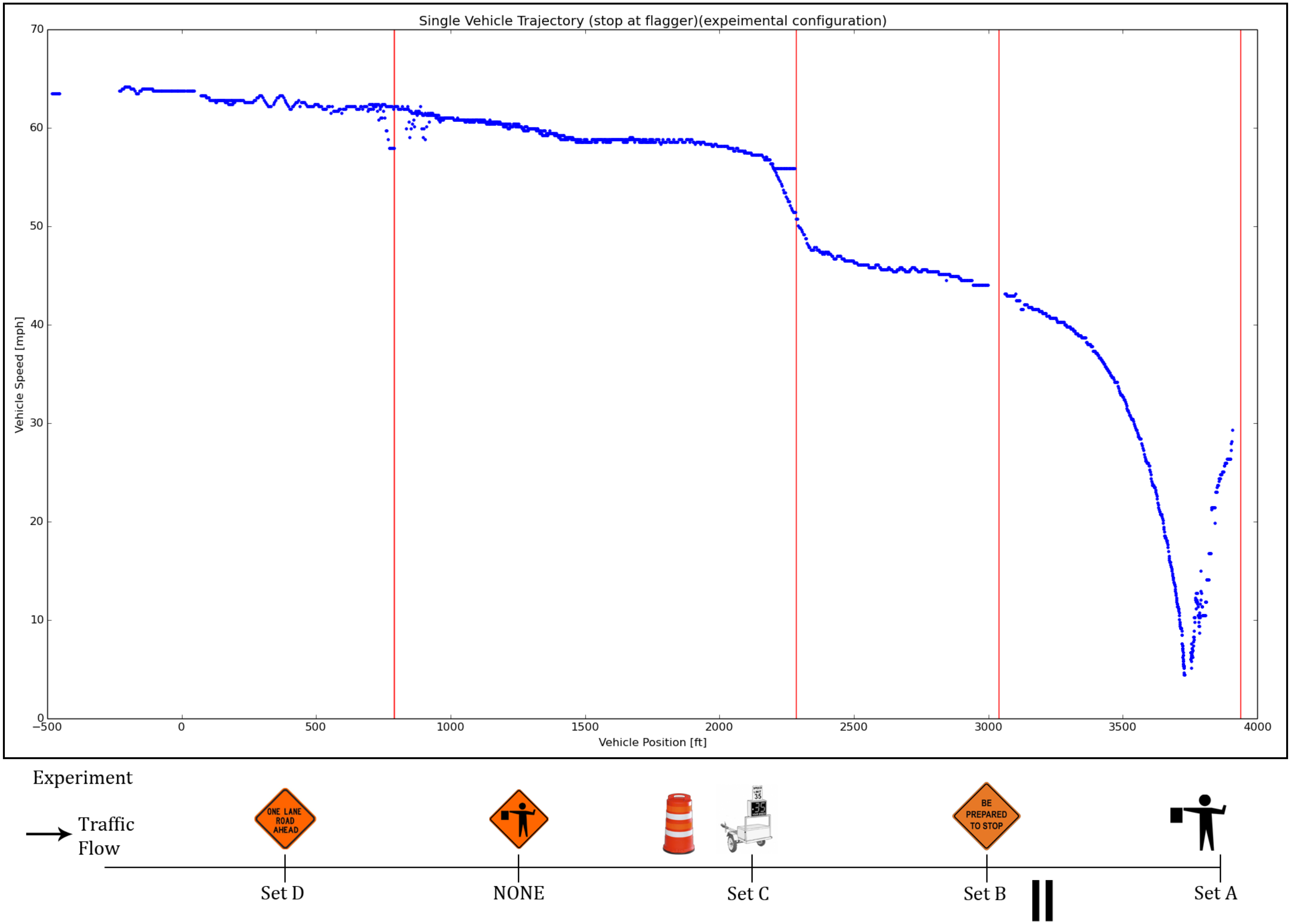

Figure 3.21 Example trajectory of a vehicle during the experimental layout that did stop at the flagger

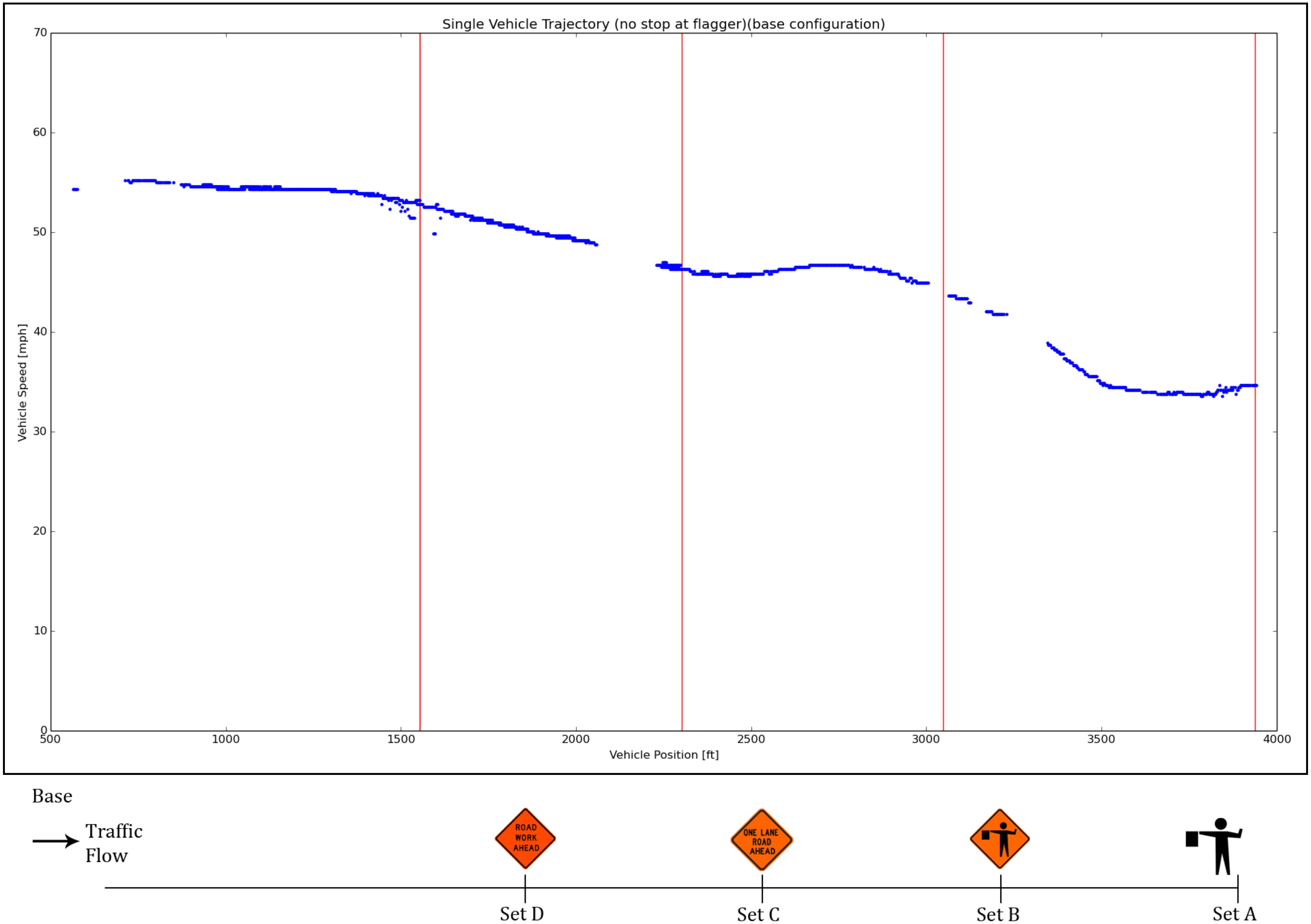

Figure 3.22 Example trajectory of a vehicle during the base layout that did not stop at the flagger

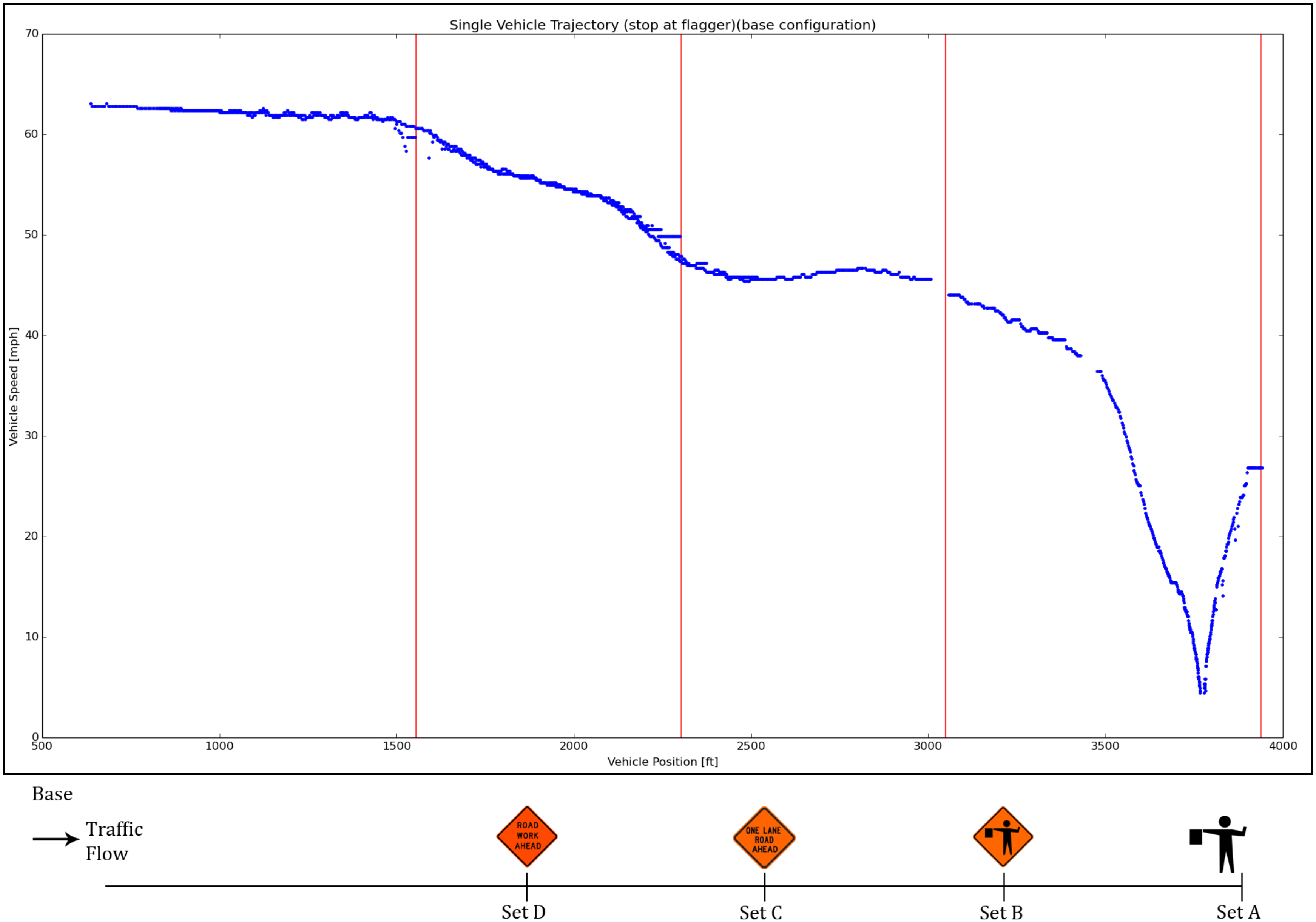

Figure 3.23 Example trajectory of a vehicle during the base layout that did stop at the flagger

3.10 DATA ANALYSIS AND OBSERVATIONS

3.10.1 Work Zone Data Processing and Analysis

This section outlines the steps followed to process the raw radar data and analyze the results for the 2015 Spring Valley work zone field experiment.

Data Collection: Radar data was collected in the field using a single computer running the software required to interface with the sensors and parse their raw message streams. This data was stored in an IPC dump file which stores the data efficiently in binary format. Data from individual sensors were all stored together in single dump files. Additionally, in these files, vehicle trajectory and position data was stored in each radar's individual coordinate frame.

Data Processing: Processing was performed to convert the raw collected data into a format that combines all the data from each sensor into a single, global coordinate frame. This involved performing transformations on the data from each sensor based on knowledge about that sensor's position and orientation within the work zone coordinate frame.

This data was further processed to extract individual vehicle trajectories. This was conducted by plotting all the trajectory data in GIS software and then selecting and extracting the points corresponding to a single vehicle trajectory. Vehicle trajectories were selected such that a selected vehicle represented a leader vehicle (i.e. any vehicle traveling in the work zone at least 30 seconds after another vehicle). This was done to ensure independence between selected vehicle trajectories.

Each vehicle trajectory was labeled to identify the following attributes:

Road condition: pavement or gravel

Signage condition: base layout or experimental layout

Flagger behavior: stopping at flagger or not stopping at flagger (per flagger's signals)

Vehicle type: heavy truck (semi) or automobile (cars, vans, light trucks)

Horn warning deployment: speeds exceeding horn trigger limit or speeds under limit

This resulted in the segmentation of individual vehicles that could then be used in the analysis of driver behavior in the work zone.

Data analysis: The goal of the data analysis was to determine the effects that the different signage conditions had on driver speeds through the work zone. The analysis represents the driver speed behavior as aggregated by distance from the flagger. The work zone is split into 100 feet bins in which vehicle speed statistics are calculated for the vehicles traveling through those areas.

Statistics are aggregated by identifying the portion of each individual vehicle trajectory contained by a particular bin. The vehicle's speed for that bin is then reported as the mean of all speeds recorded for that vehicle while in that bin. This is then repeated for all 40 bins making up the work zone. Statistics data is then aggregated for all vehicles passing through the work zone.

Collections of statistics were generated for a number of different trajectory attribute combinations. For example, statistics were generated that separated all trajectories into two groups based on the signage condition. That allowed for separate sets of statistics to be generated for vehicles experiencing the experimental layout and the base layout. The distribution of vehicle speeds for each bin could then be compared between these groups to determine the significance of difference in the speed profiles. This allows for conclusions to be drawn about the effects of the two signage conditions.

For all analyses, data was only used for vehicles traveling on pavement and vehicles classified as automobiles. As discussed above, all trajectories examined were from leader vehicles and represented vehicles whose trajectories were captured along the entire work zone.

3.10.1.1 Speed Distribution vs Distance Analysis

The speed distribution plots allow us to look at the difference of the speeds as the vehicles approach the flag operator. It is important to keep in mind that the experimental layout is longer by 750 feet as compared to the base layout so the following graph (Figure 3.24), does not compare the speeds at the same location but at the first instance the drivers are informed about the existence of the work zone.

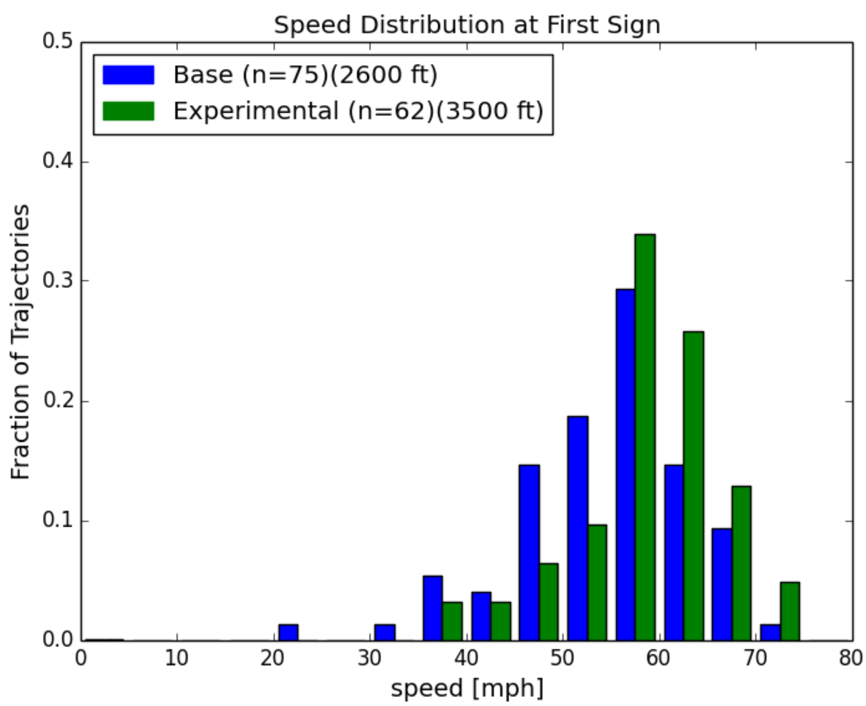

Figure 3.24 Speed distributions at first sign seen by driver

The shape of both distributions looks close to normal which suggest that there are no reasons to suspect external influence upstream of the work zone. The experimental layout days exhibit higher speeds on the approach to the work zone which can be an effect of the local road environment. This location in the experimental days (750 feet upstream of the equivalent location on the base layout) is upstream of a vertical curve that restricts visibility to the work zone. Noteworthy is that during the base condition days the drivers had no visibility of the work zone until they were close to the location of the first sign on the experimental layout. One would think that having earlier warning about a work zone would had caused the experimental days to exhibit lower speeds and not higher. This suggests that far upstream the work zone where only the color and location of the first sign is visible the drivers feel no interest in changing their speed.

Figure 3.25 shows the distribution of speeds 2,600 feet upstream of the flag operator. This is the location of the first sign on the base layout and the second sign on the experimental layout. As we can see, speeds are similar with a minor reduction during the experimental days. The distribution of speed under the experimental layout has lost its normal distribution form suggesting that some of the subjects have been affected from the message carried over by the first sign. This difference can be seen in the double Figure 3.26 in which the right chart shows drivers clearly favoring slower speeds as compared to their earlier condition.

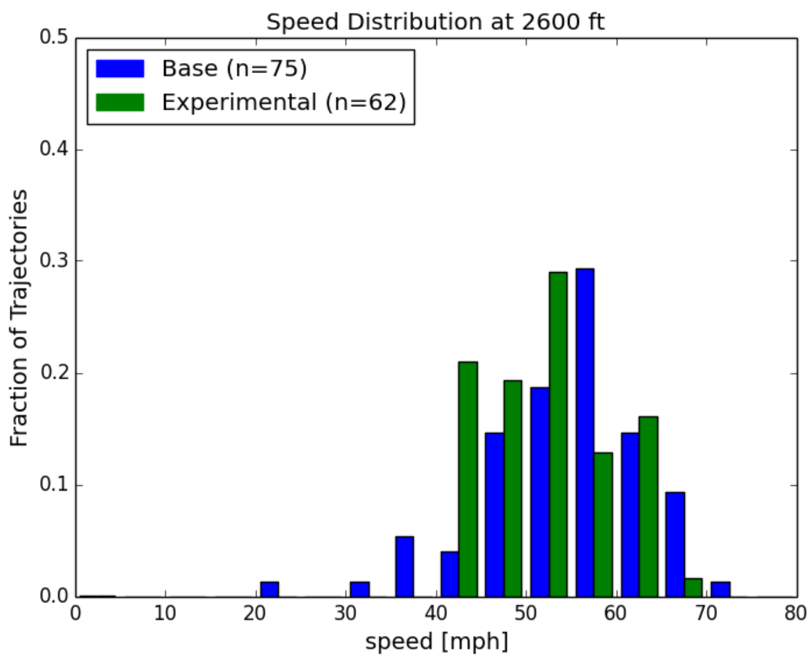

Figure 3.25 Speed distributions at 2,600 ft upstream of flag operator (first sign of Base layout)

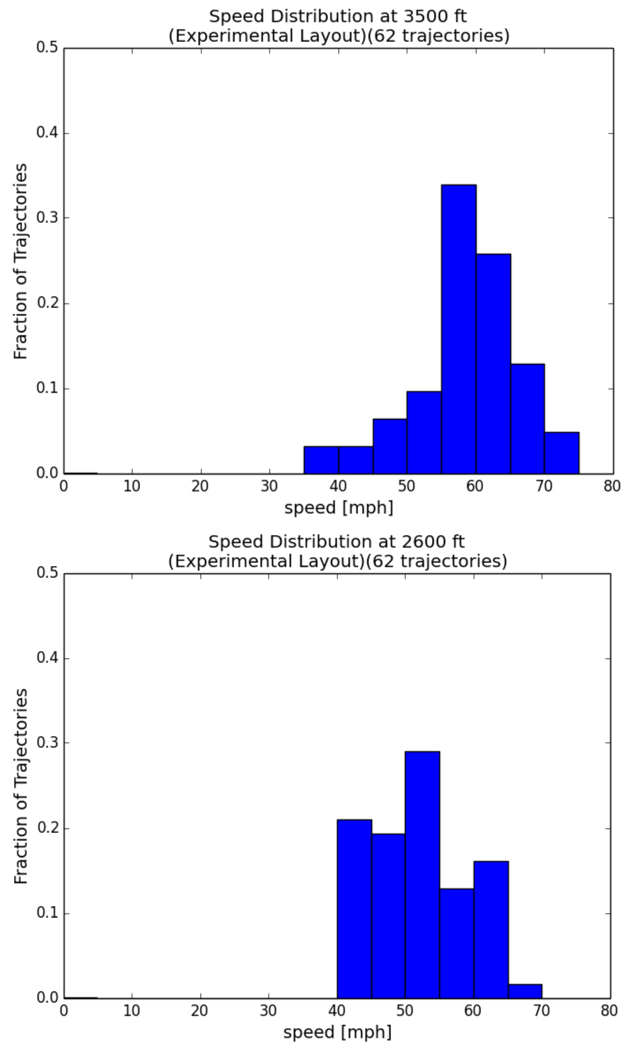

Figure 3.26 Speed distributions at first and second sign under experimental layout

As the drivers are moving closer to the work zone, 1,800 feet from the flag operator, we observe a very small additional reduction in speed, as compared to 800 feet upstream from this location, in both layouts, specifically from the people speeding way above the posted speed limit. The mean is still around the speed limit of 55mph. In the experimental layout, although it has started at higher speeds now it displays clearly lower trends s compared to the base. This distance represents the location of the speed trailer in the experimental layout and the location of the second sign (one lane road ahead) in the base layout. From the pair of speed distributions on the first and second signs of the base layout (Figure 3.28) and comparing them to the first and second signs on the experimental layout (Figure 3.26) we observe that, although the Base layout speed has lost its normal distribution form indicating influence on the drivers, the speed reduction is smaller than the one observed in the experimental layout at the comparable location.

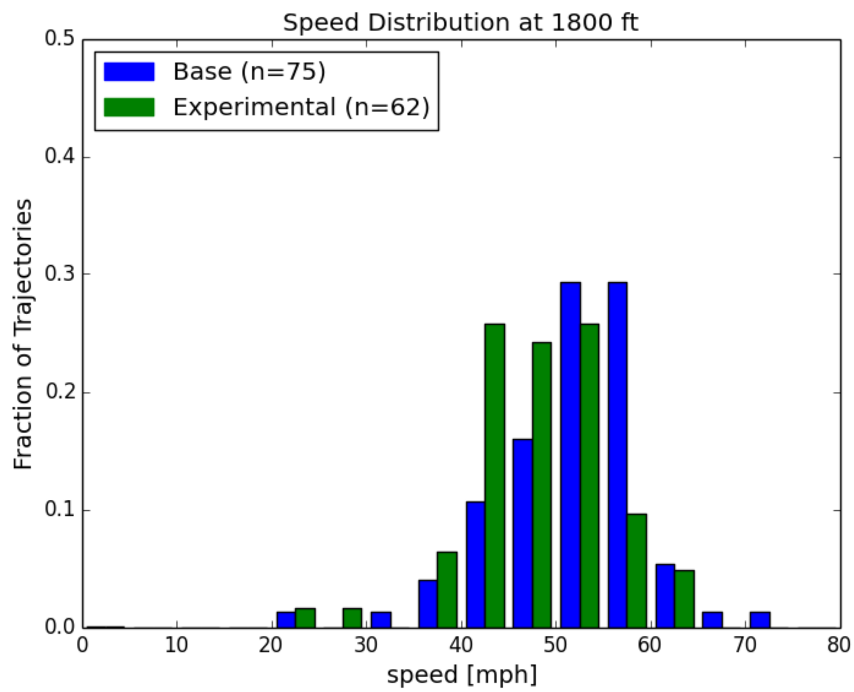

Figure 3.27 Speed distributions at 1,800 ft upstream of flag operator

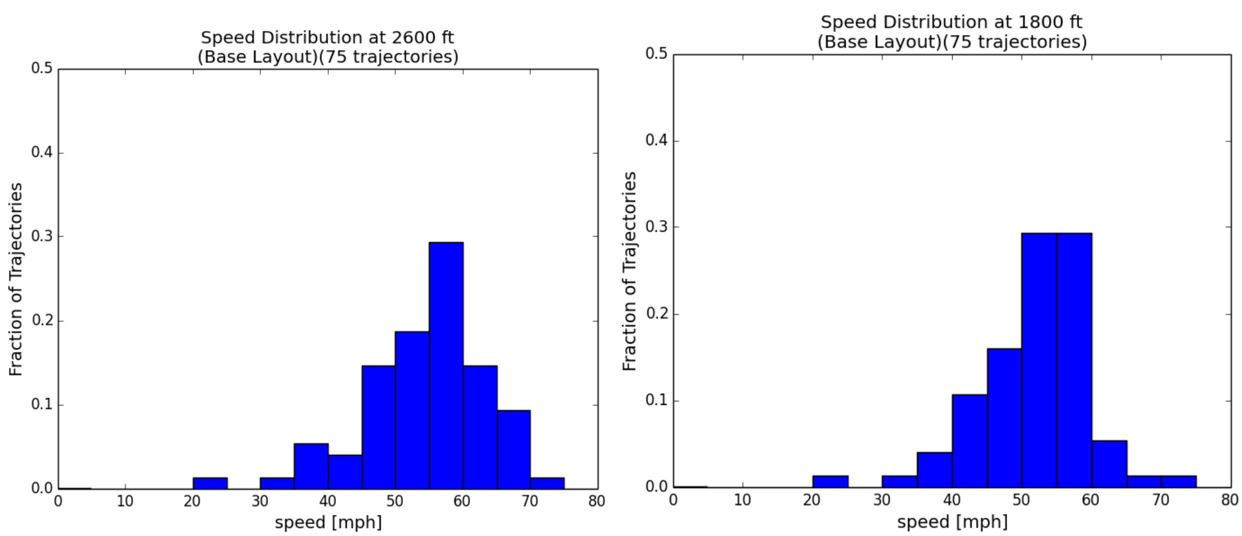

Figure 3.28 Speed distributions at first and second sign under base layout

As Figure 3.29 suggests, when vehicles have reached a distance of 1400 feet from the flag operator they have started to normalize their speed distribution in both cases. As the figure shows, the experimental layout mean is around 45 mph while the mean in the base layout is slightly higher at 50 mph but with a greater dispersion resulting in a higher percentage of vehicles above the mean compared to the experimental layout.

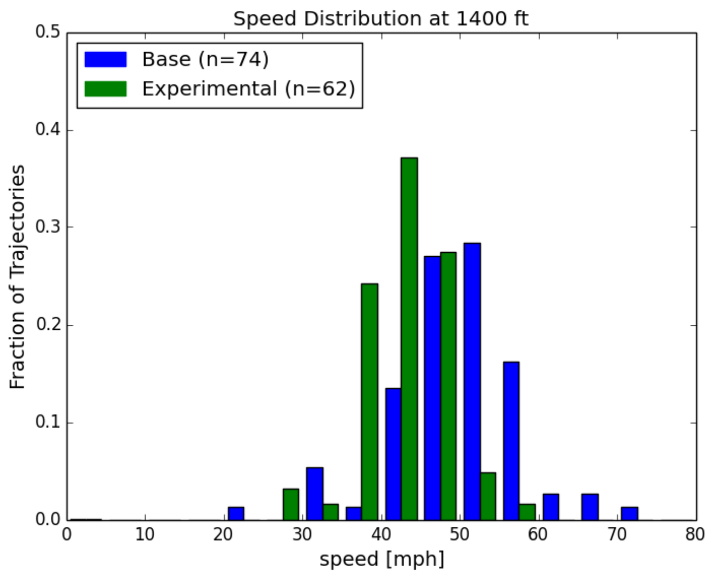

Figure 3.29 Speed distributions at 1,400 ft upstream of flag operator

To look the driver speed adaptation behavior strictly from the point of view of the number of control devices encountered we can compare in succession the following figure pairs. Figure 3.30, as explained earlier, shows the speeds 500 feet upstream of the first sign encountered in both layouts. The experimental layout displays a higher speed distribution. Both cases show no sign of influence on the drivers.

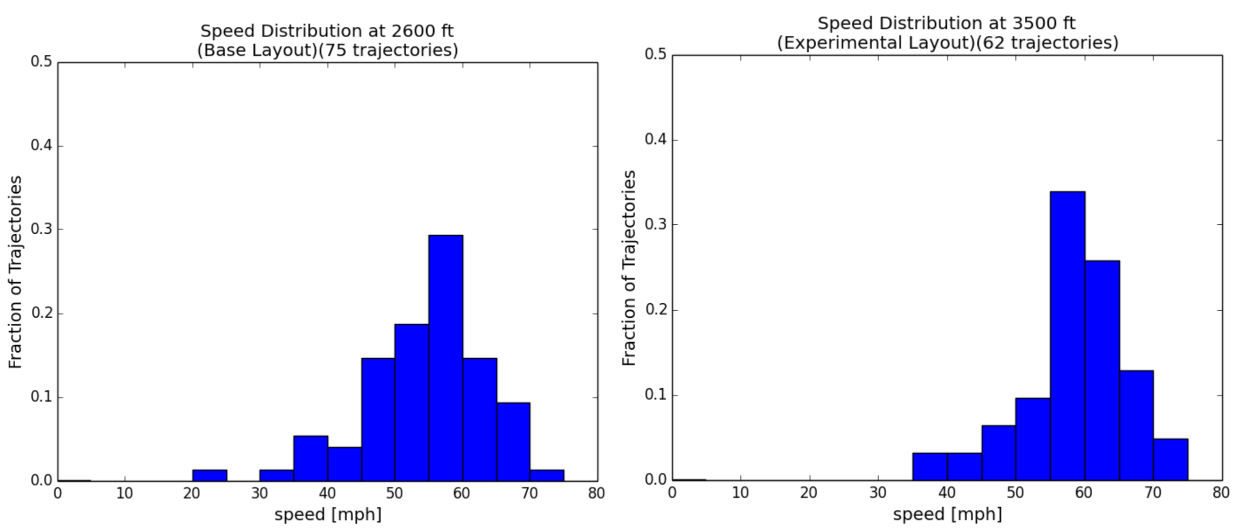

Figure 3.30 Speed distributions at first sign, base layout (left), experimental layout (right)

Figure 3.31 is the speed 500 feet upstream of the second traffic control sign on both alternatives. Both layouts show signs of speed adaptation but the experimental layout shows a stronger speed reduction.

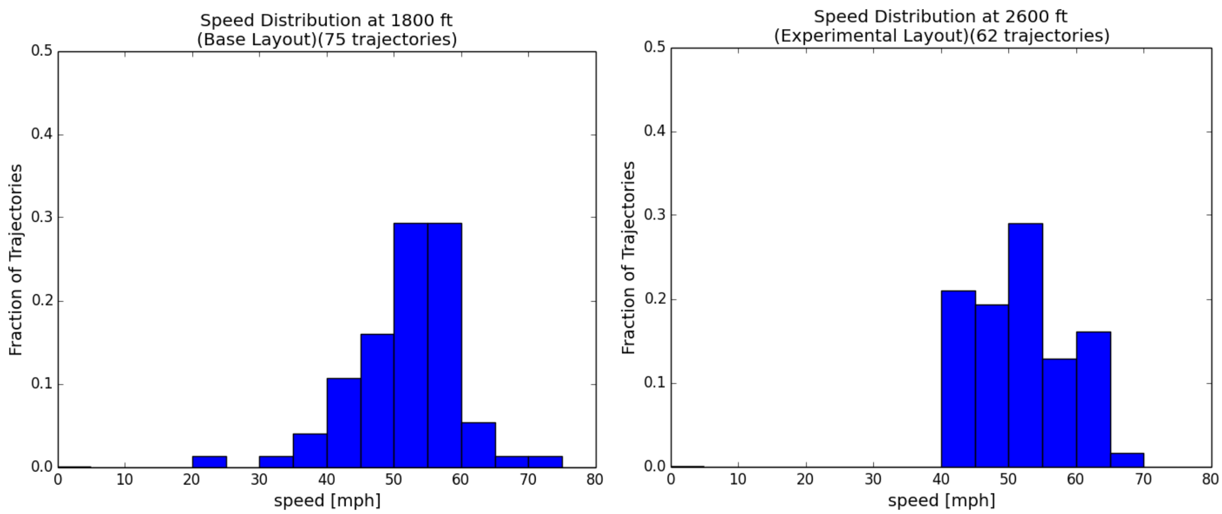

Figure 3.31 Speed distributions at second sign, base layout (left), experimental layout (right)

Figure 3.32 shows the speeds 500 feet upstream of the third traffic control location. In the case of the experimental layout this is the location of the trailer. This means that drivers with speeds higher than 45 mph have not yet experienced the horn barrel but can probably see the flashing speed warning on the trailer. We observe a higher percentage of drivers in the experimental layout reducing their speeds to 45 mph and lower bringing the mean speed to around 48 mph, while the base layout shows a mean of around 52 mph.

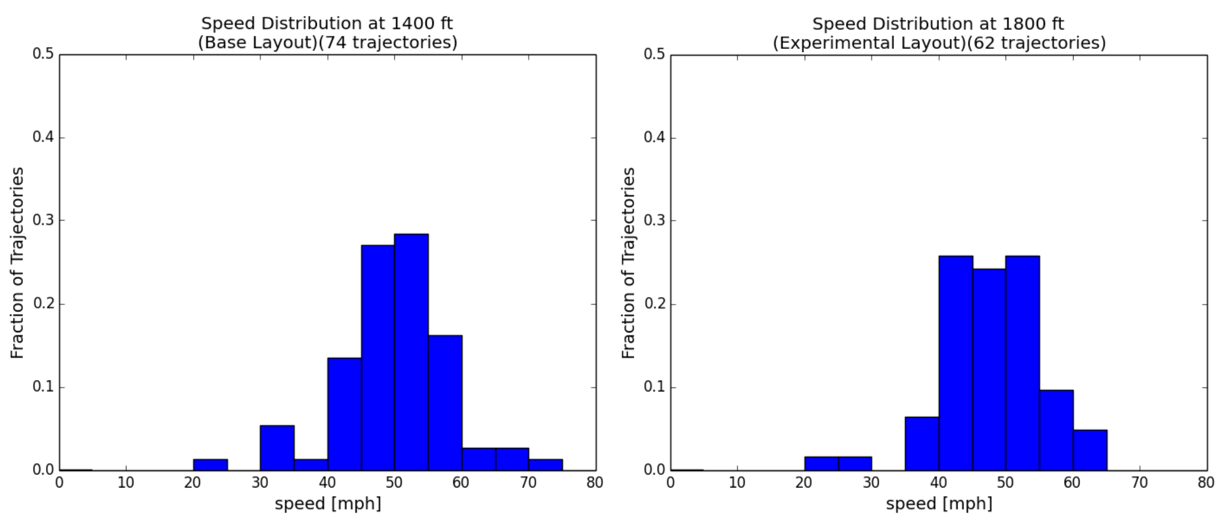

Figure 3.32 Speed distributions at third sign, base layout (left), experimental layout (right)

Figure 3.33 shows the speed distributions 500 feet upstream of the flag operator in the case of the base layout and the same distance upstream of the fourth traffic control device (rumble strips) in the case of the experimental layout. In both cases the mean speed I at or below 45mph although the experimental layout has a higher percentage above the mean. At this location the drivers at the base layout can clearly see the flag operator and know that they will have to stop while in the experimental scenario more than twice that distance yet to cover. Having the speeds being equal at this point we see that the drivers in the base layout have to decelerate more rapidly when they come in view of the flag operator.

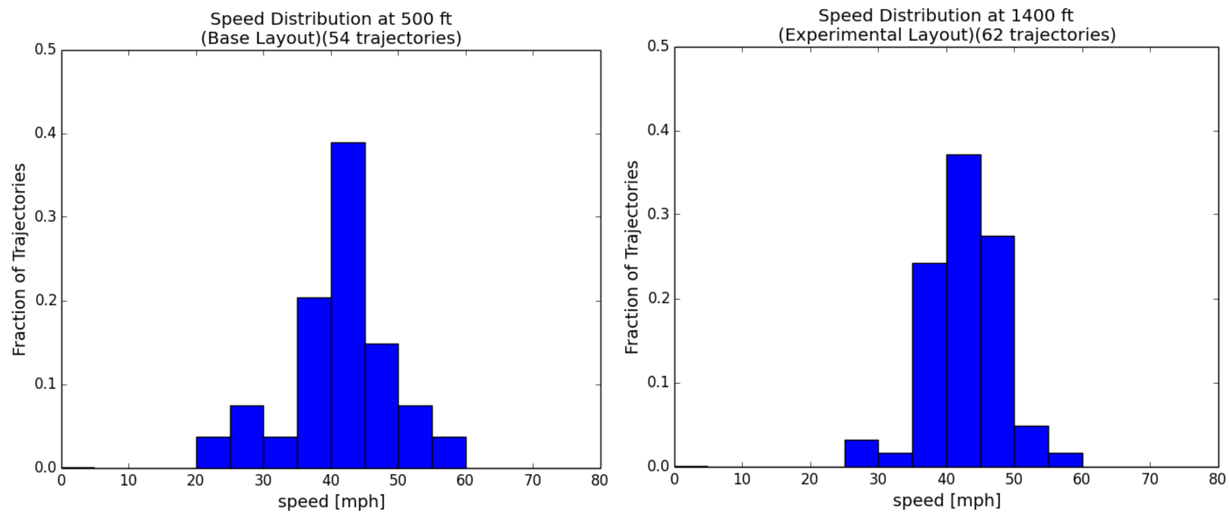

Figure 3.33 Speed distributions at fourth sign, base layout (left), experimental layout (right)

Figure 3.34 shows the speeds in both cases after all traffic control devices, 500 feet upstream of the flag operator. The speeds are comparable with the experimental layout showing a noticeable lower mean speed and the base layout showing higher percentages at speeds of 45 and 50 mph.

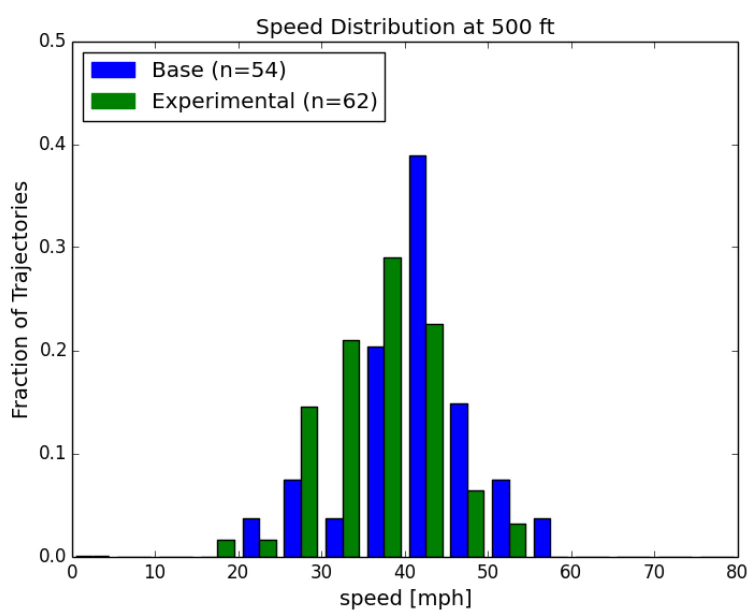

Figure 3.34 Speed distributions at 500 ft upstream of flag operator

3.11 SPEED ADAPTATION COMPARISONS

The following section contains the comparison of the speeds drivers selected in their approach to the work zone under the experimental and base layouts during the 2015 field experiment. These figures are the results of a statistical analysis of the collected data grouped in various ways in an attempt to uncover the underlying driver behavior. Each combination graph contains a line representing the median speed over distance. The shadowed area around each line marks the 75^{th} and 25^{th} percentile speeds in each location. The black box contains the range of speeds/distances where the two work zone layouts have produced speed differences that are statistically significant. The respective layouts are also shown in the figures. For completeness the results from the 2014 field experiment are also included.

Figure 3.35 presents the speeds collected from all leading vehicles under the two work zone traffic control alternatives. The experimental layout in general produced lower speeds but the speeds of the vehicles substantially differ from the base layout case as the drivers approach the speed trailer and horn barrel. While under the base layout we note a steady deceleration up until the last sign before the flag operator, under the experimental layout we note a more complex behavior. Experimental layout drivers start their deceleration earlier than their counterparts under the base layout. This is logical since the experimental layout starts 750 feet upstream of the base layout. Until approximately 400 feet upstream of the speed trailer the experimental layout drivers follow a similar steady deceleration. As they approach the speed trailer, approximately at the location of the horn, the drivers apply a greater deceleration. It is interesting to note that this greater deceleration brings the median speed below 45mph after the speed trailer at which point the drivers under the experimental layout accelerate slightly to reach 45mph. The aforementioned acceleration last until approximately 400 feet upstream of the rumble strips at which point the experimental layout drivers start a stronger deceleration in order to stop at the flag operator. Although there is strong evidence that the speed trailer causes the drivers to decelerate at a higher rate, there are no evidence that the rumble strips have any effect on speed selection. In general, we can confidently say that the experimental layout produces slower speeds in the approach to the work zone and, at least in the case of the speed trailer, and in extends we can be certain that it succeeds in attracting the attention of the drivers.

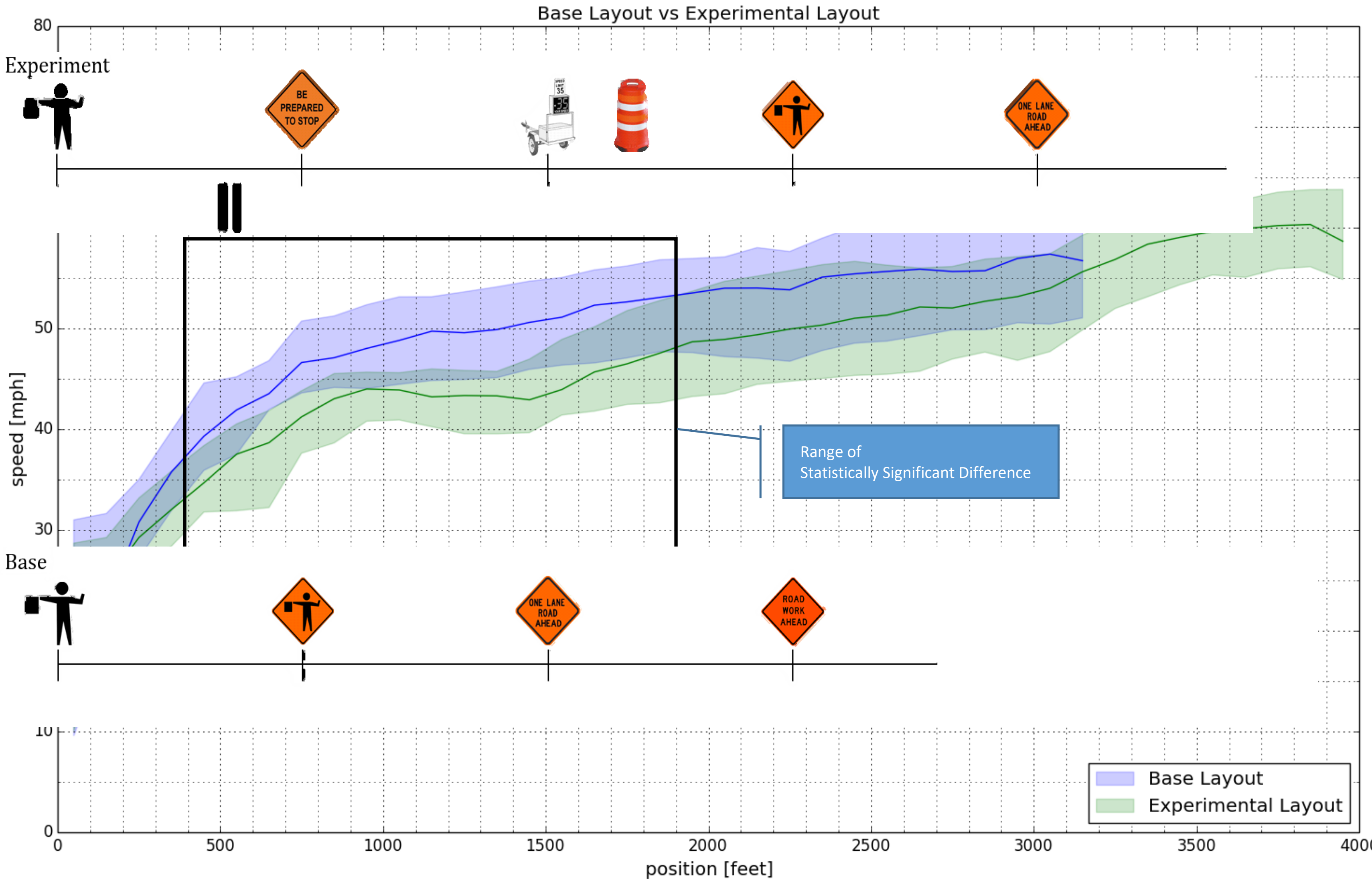

Figure 3.35 Speed distributions vs distance under the base and experimental layouts

Figure 3.36 and Figure 3.37 present the distributions of speed under the base and the experimental layouts respectively. In comparing the two results it is worth noting that under the base layout the dispersion of speeds is considerably higher and includes a few high speed outliers while the dispersion of speed, as expressed by the 75th and 25th percentile bounds, is narrower and presents no high speed outliers. The two are comparable at the earliest points upstream of the work zone which suggest that there was minimal influence of exogenous factors other than the work zone layout.

Figure 3.39 attempts to separate the drivers under the experimental layout that experienced the horn vs the ones that did not. Naturally, the ones that experienced the horn are the ones that were speeding so the difference in speed levels is not informative but the deceleration patterns is telling of drivers' reaction to the horn and the trailer. In both cases the drivers reach a speed lower than 45mph after the trailer and accelerate slightly. This suggest that the trailer has an effect on driver behavior regardless of the horn. Although both populations initially have similar speeds, speeders are displaying a much lower deceleration as they enter the work zone boundary; still having speeds well above the speed limit. Although non-speeders employ a steady deceleration between the first warning sign and before the rumble strips, speeders display a very low, practically zero, deceleration till they reach the horn and be in view of the trailer at which point they decelerate sharply to bring themselves below or at the work zone speed limit. Clearly, although speeders have been informed of the work zone existence, they do not show signs of speed compliance until the more dynamic warnings of the horn and the trailer. A hypothesis is that they comply because they realize that their speed is monitored. From Figure 3.40 we see that speeders under the experimental layout are also well below the speeding drivers under the base layout and reach legal speeds well upstream of the flag operator.

Figure 3.41 shows the statistics of the driver population that did not have to stop at the flag operator because either were the only vehicles on the scene (both ways) or they were the next vehicle after that direction was given the right-of-way. Again we see a statistically significant lower speed pattern under the experimental layout as compared to the base one although both populations reach similar speeds, around 30mph, at the flag operator.

Figure 3.44 shows the speed adaptation of the driver population that had to stop at the flag operator. Note that these are the first vehicles in line and no other vehicles were in queue at the flag post. Speeds between these two groups are lower under the experimental layout but only statistically significantly different right after the trailer and before the rumble strips.

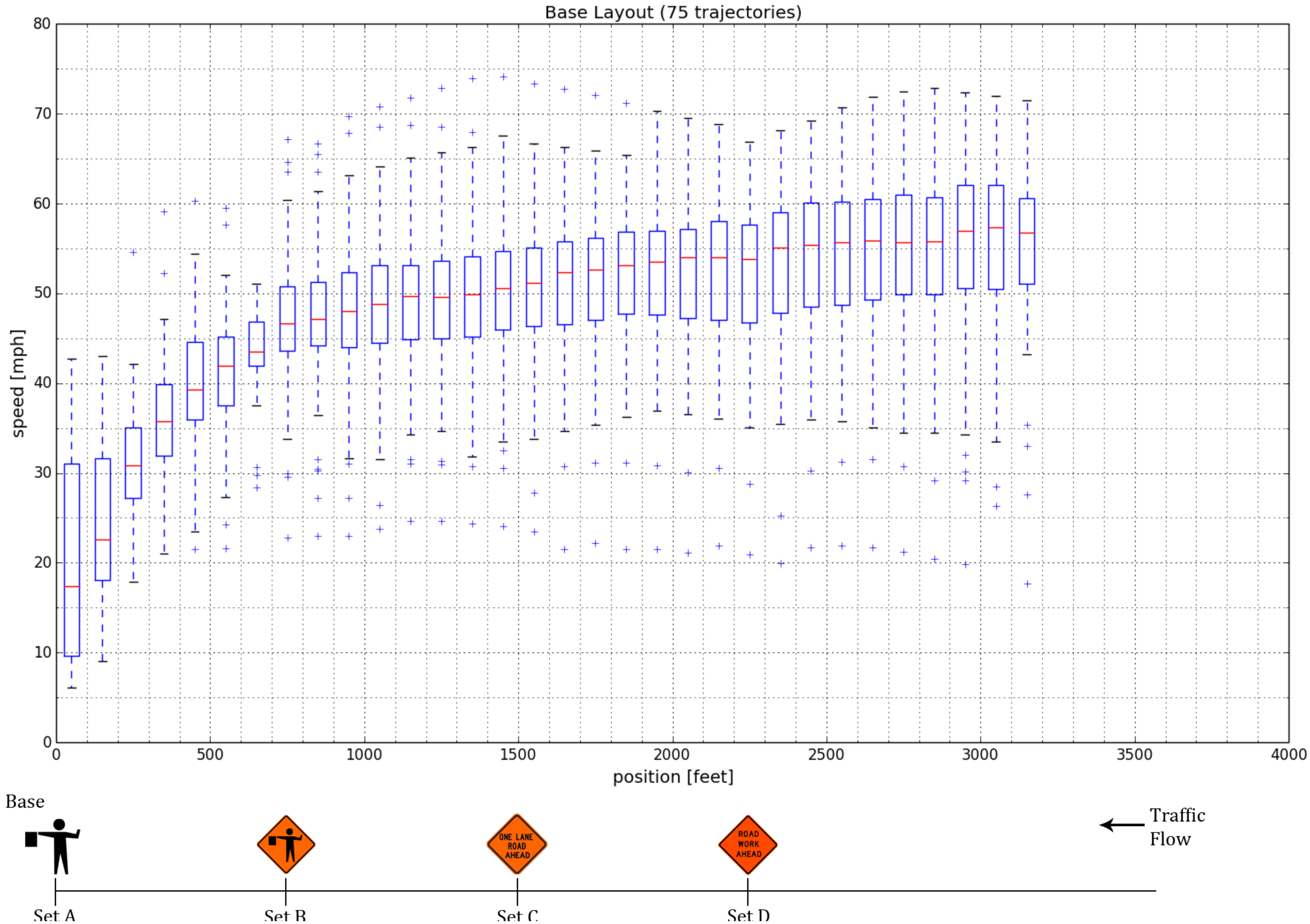

Figure 3.36 Distribution of speeds vs distance under base layout

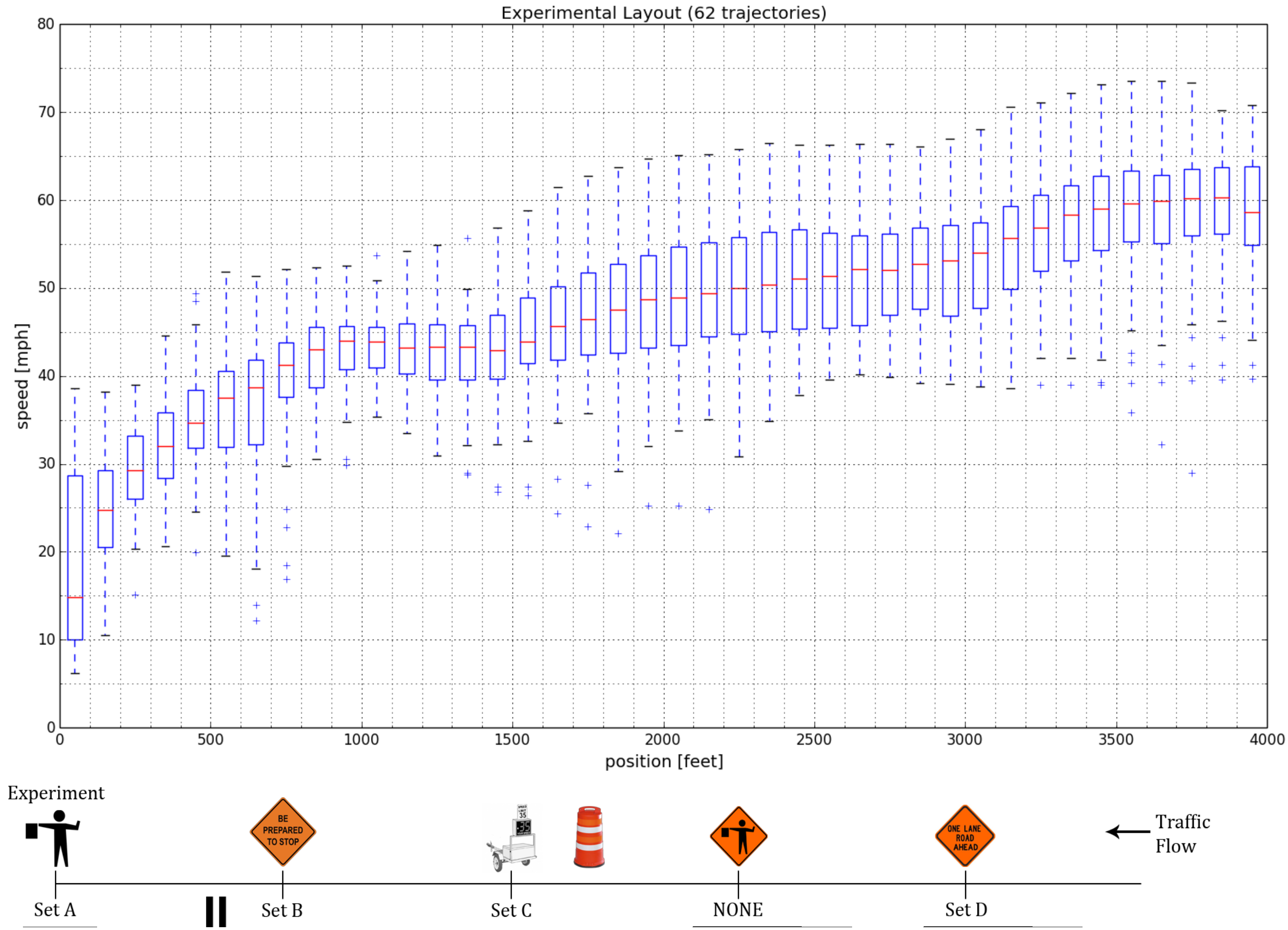

Figure 3.37 Distribution of speeds vs distance under experimental layout

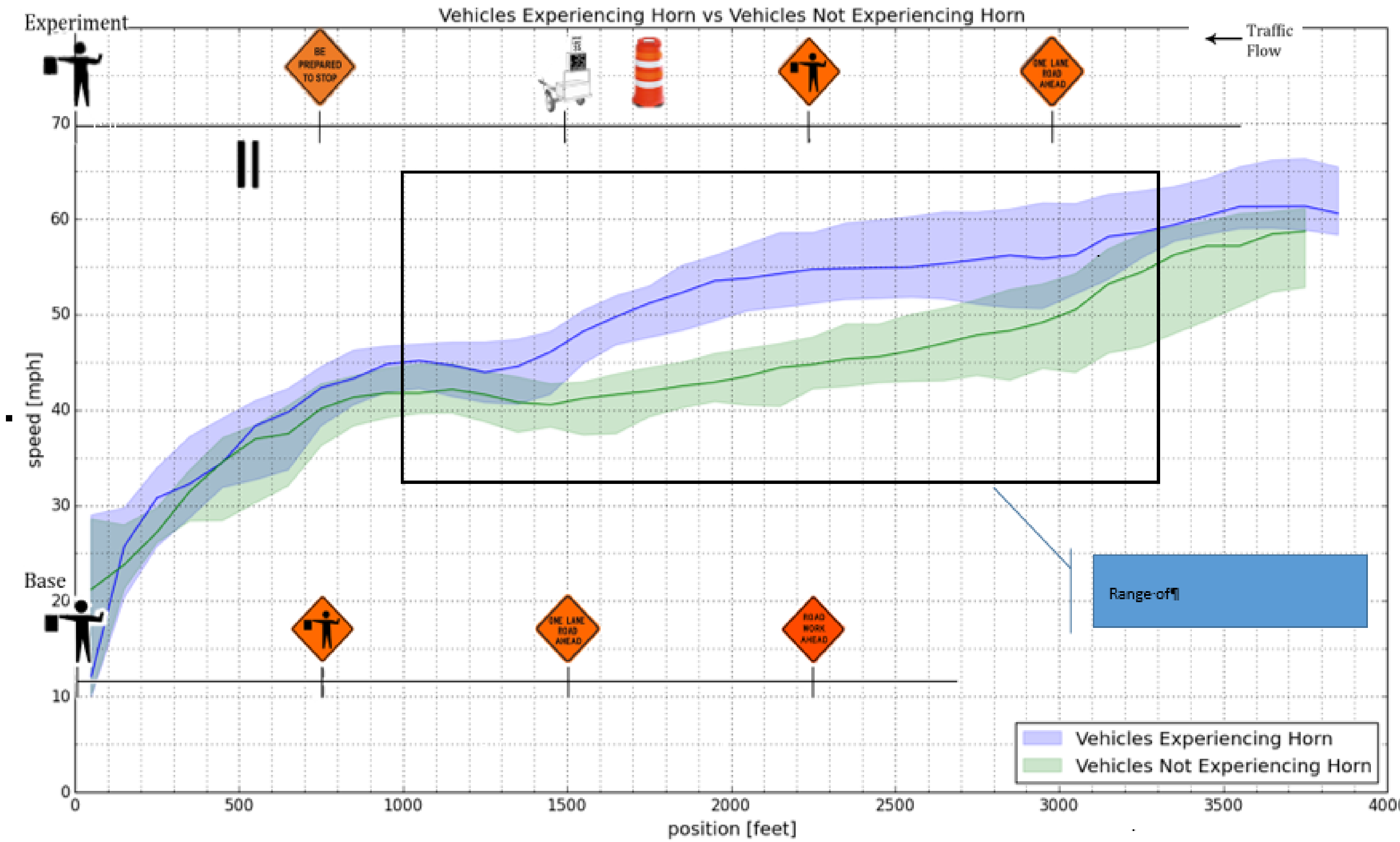

Figure 3.38 Speed distributions vs distance under experimental layout. Speeders vs normal drivers.

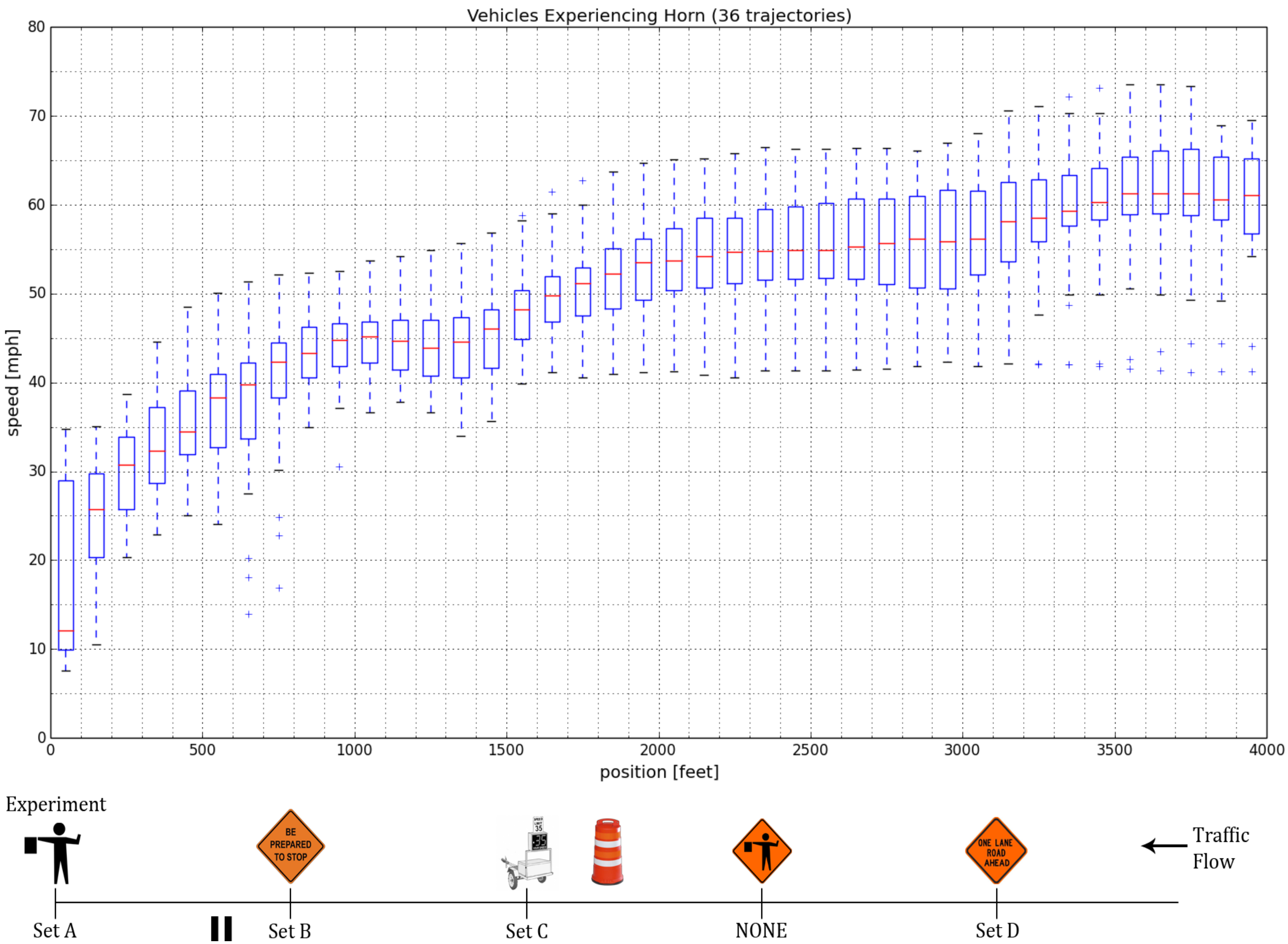

Figure 3.39 Distribution of speeds vs distance for vehicles experiencing the horn (speeders)

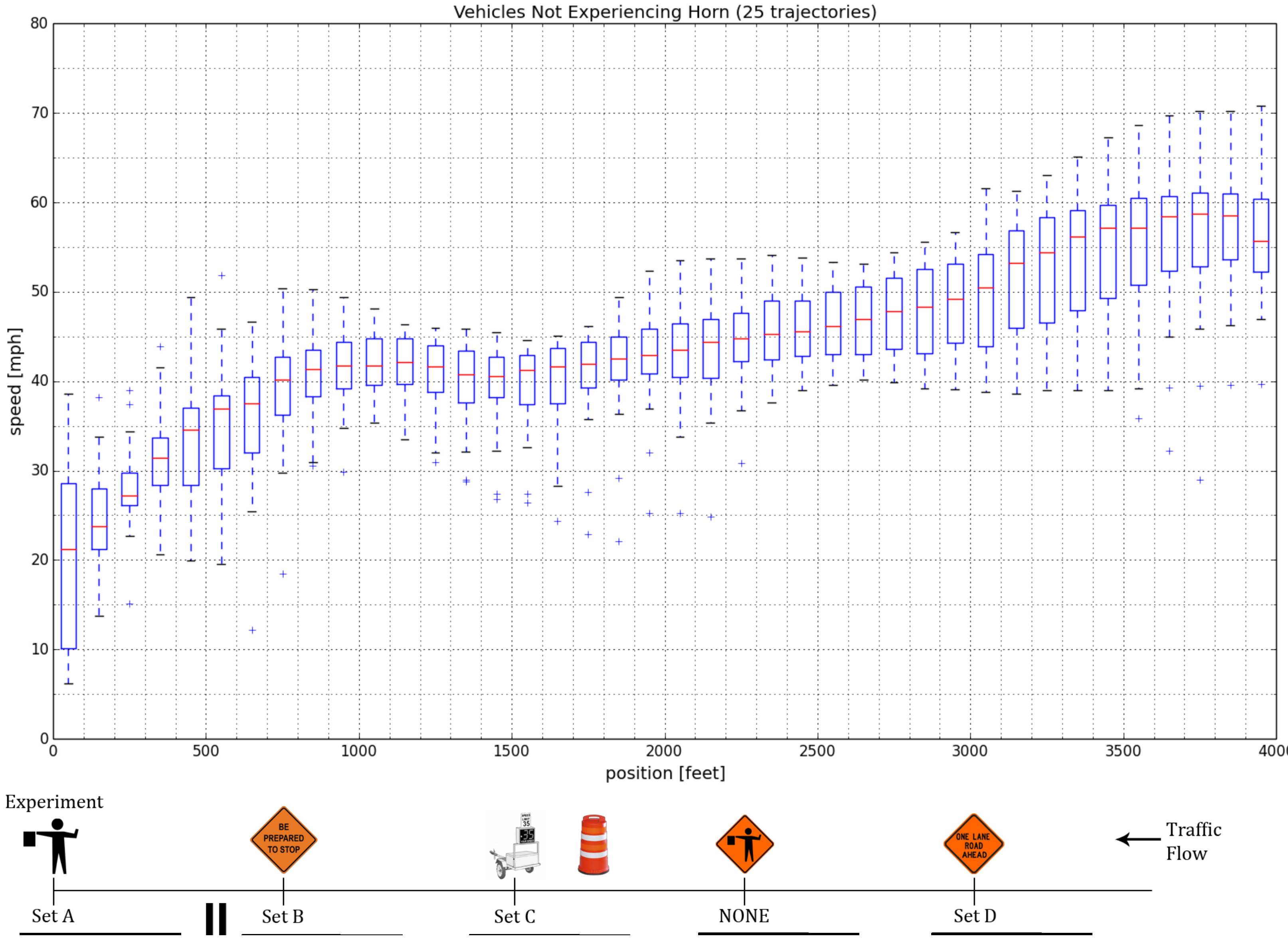

Figure 3.40 Distribution of speeds vs distance for vehicles that did not activate horn (normal)

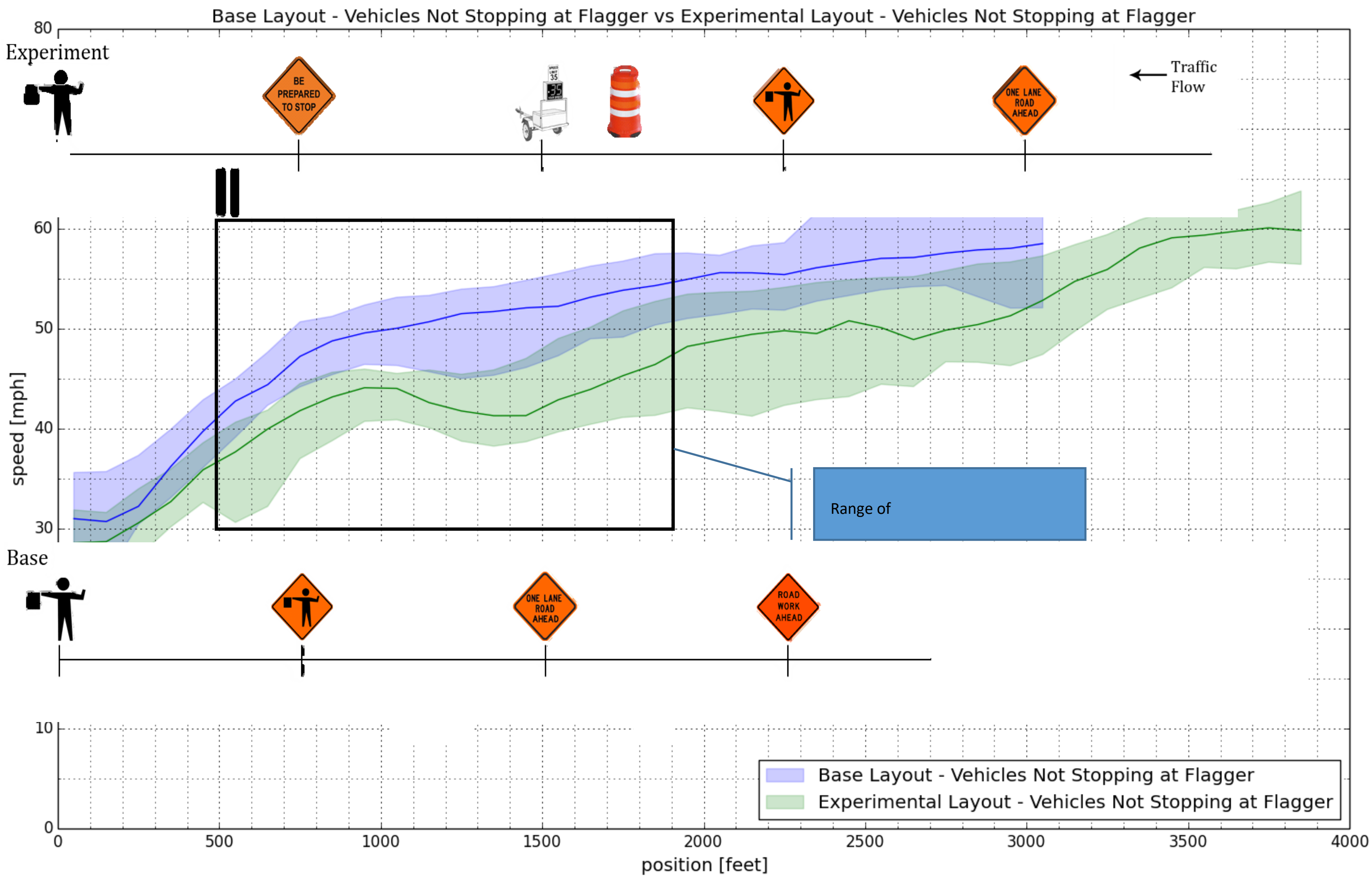

Figure 3.41 Speed distributions vs Distance. Vehicles that didn't have to stop at flag operator.

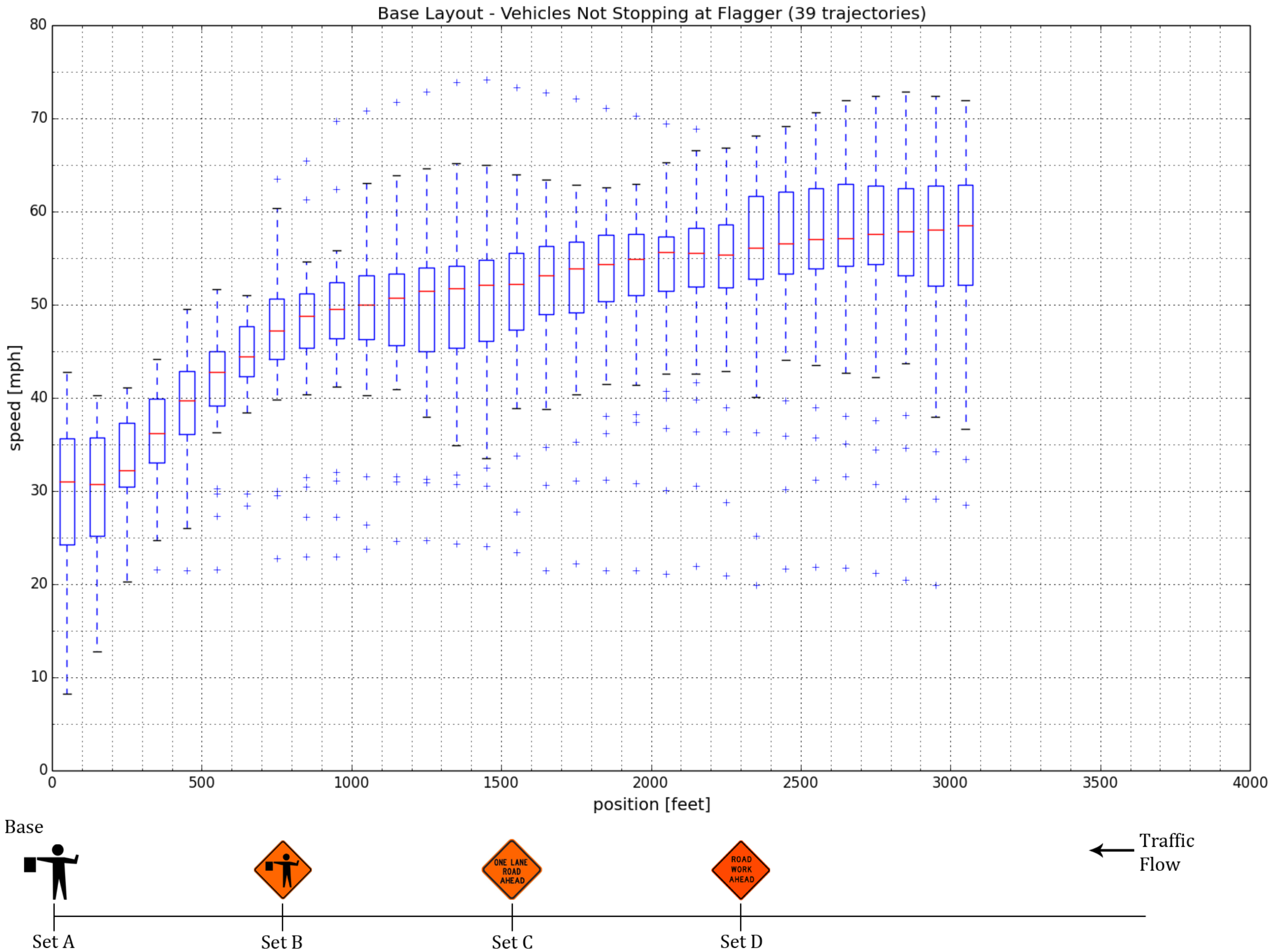

Figure 3.42 Distribution of speeds vs distance of vehicles not stopping at flag operator under base layout

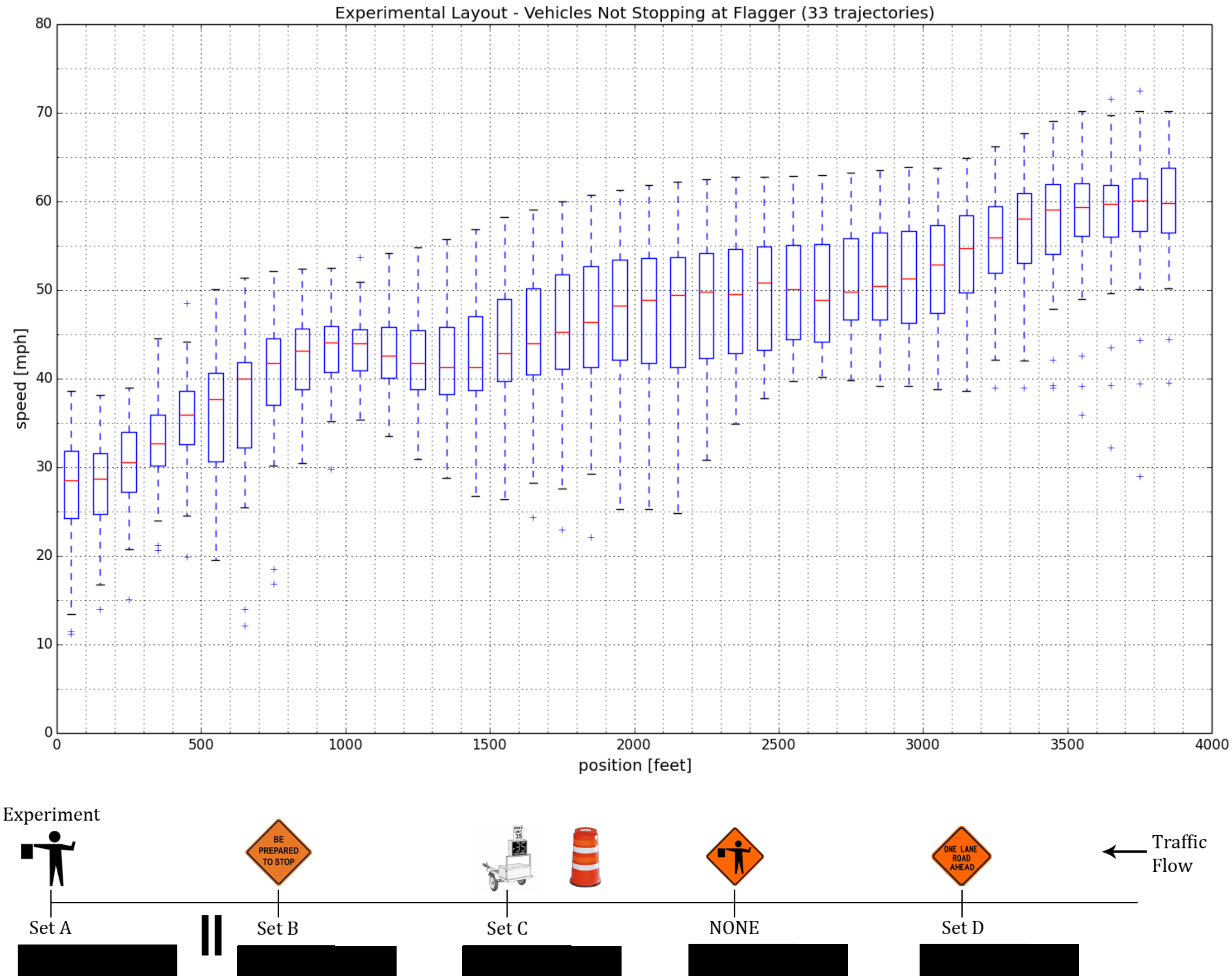

Figure 3.43 Distribution of speeds vs distance of vehicles not stopping at flag operator under experimental layout

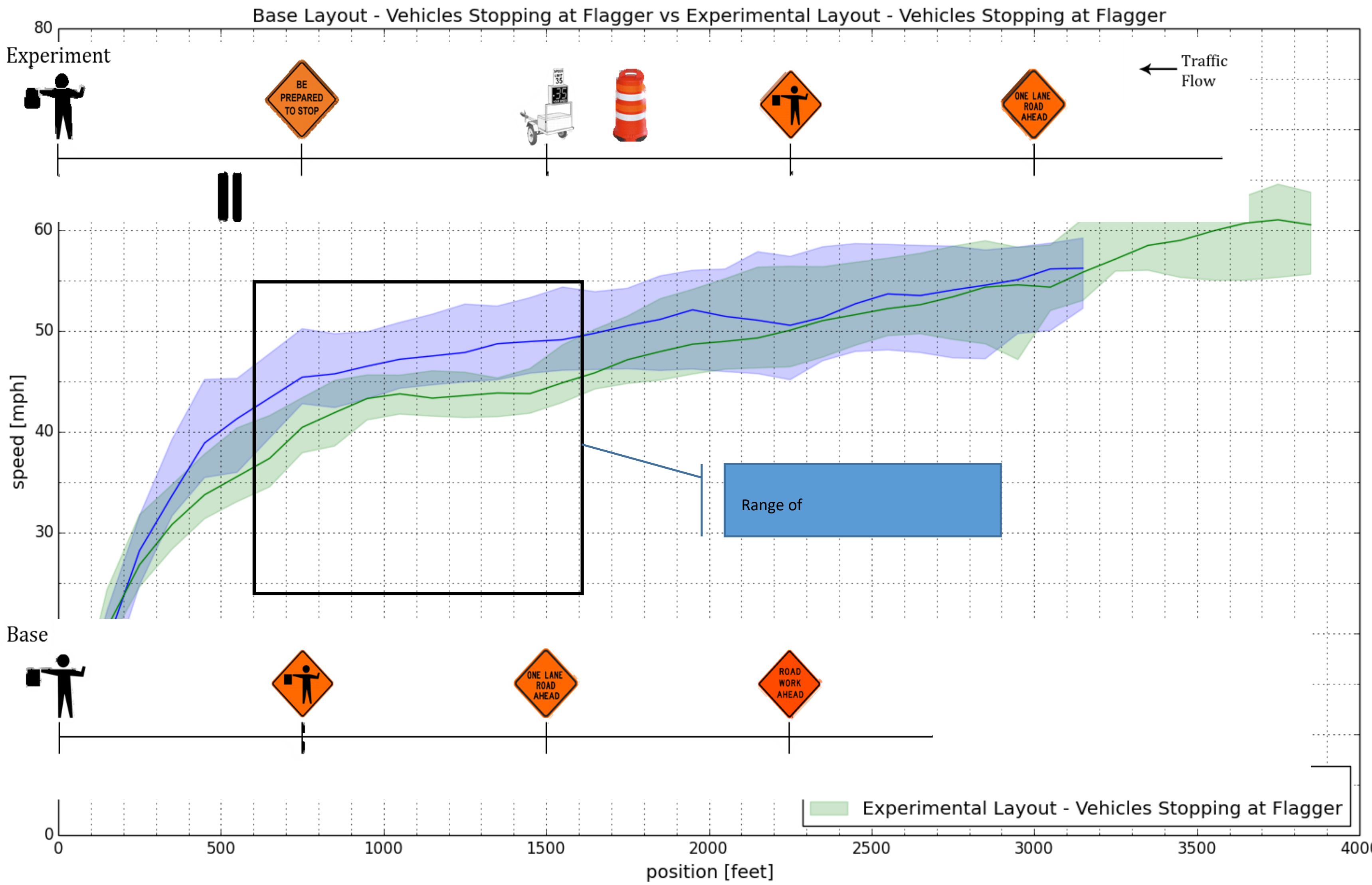

Figure 3.44 Speed distributions vs distance. Vehicles that had to stop at flag operator.

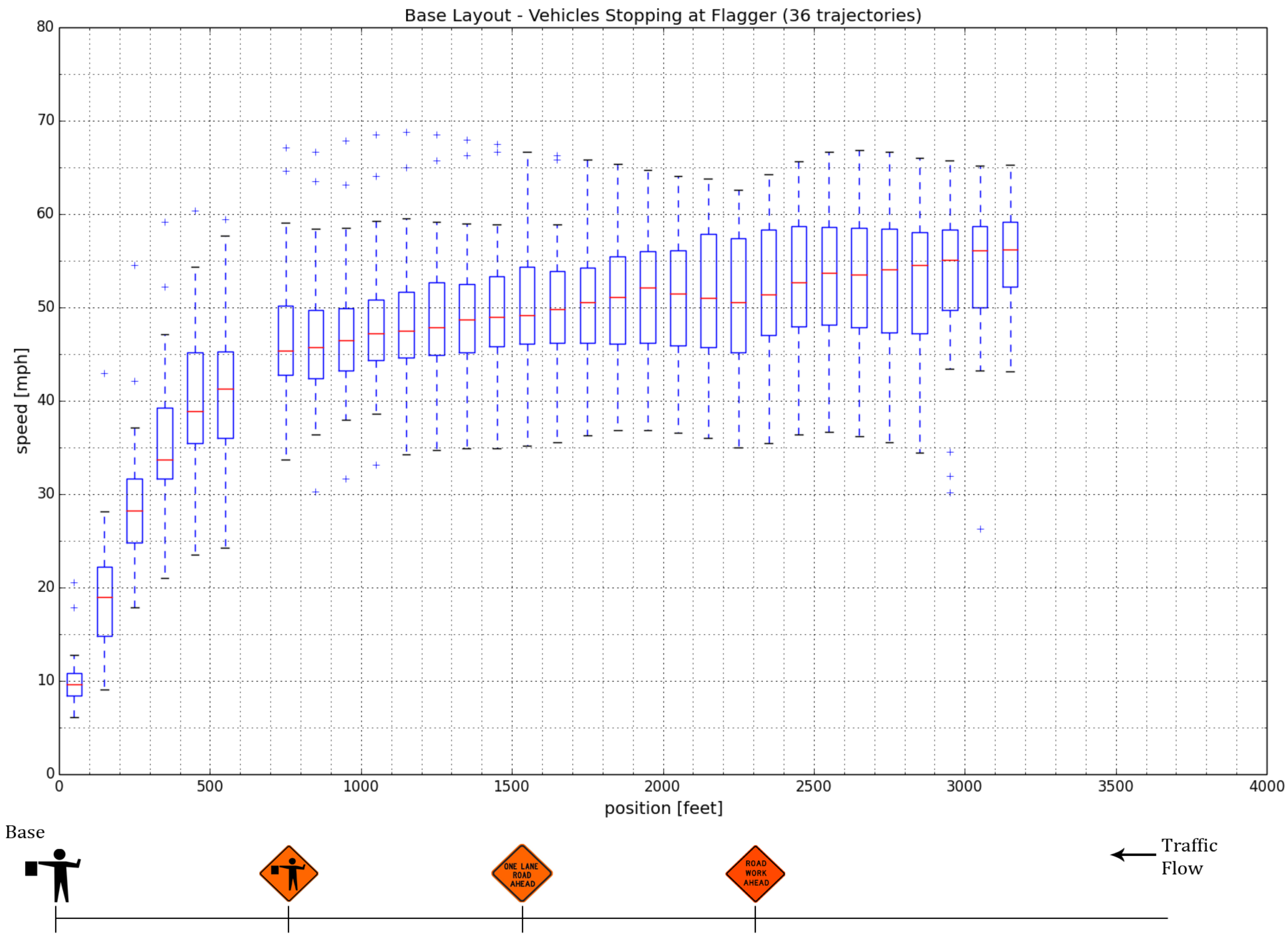

Figure 3.45 Distribution of speeds vs distance of vehicles that stopped at flag operator under base layout

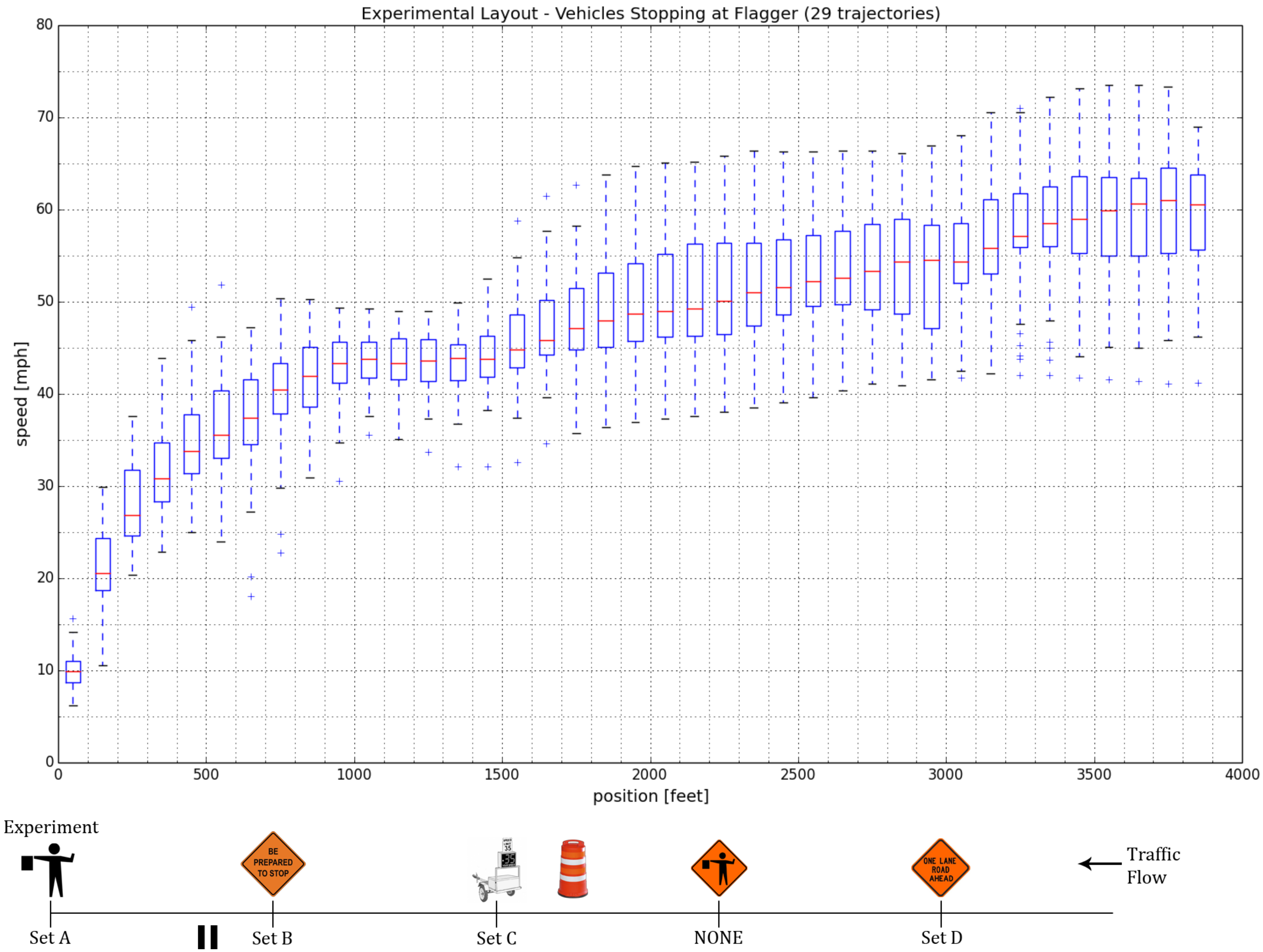

Figure 3.46 Distribution of speeds vs distance of vehicles that stopped at flag operator under experimental layout

Figure 3.47 and Figure 3.48 show the results from the 2014 field experiment and are included here for completeness. In the earlier discussion and figures all data were from leader vehicles so the more appropriate discussion can be based on Figure 3.48. Although the population in 2014 was considerably smaller than the population captured in 2015, we still see the same behavior in terms of speed adaptation.

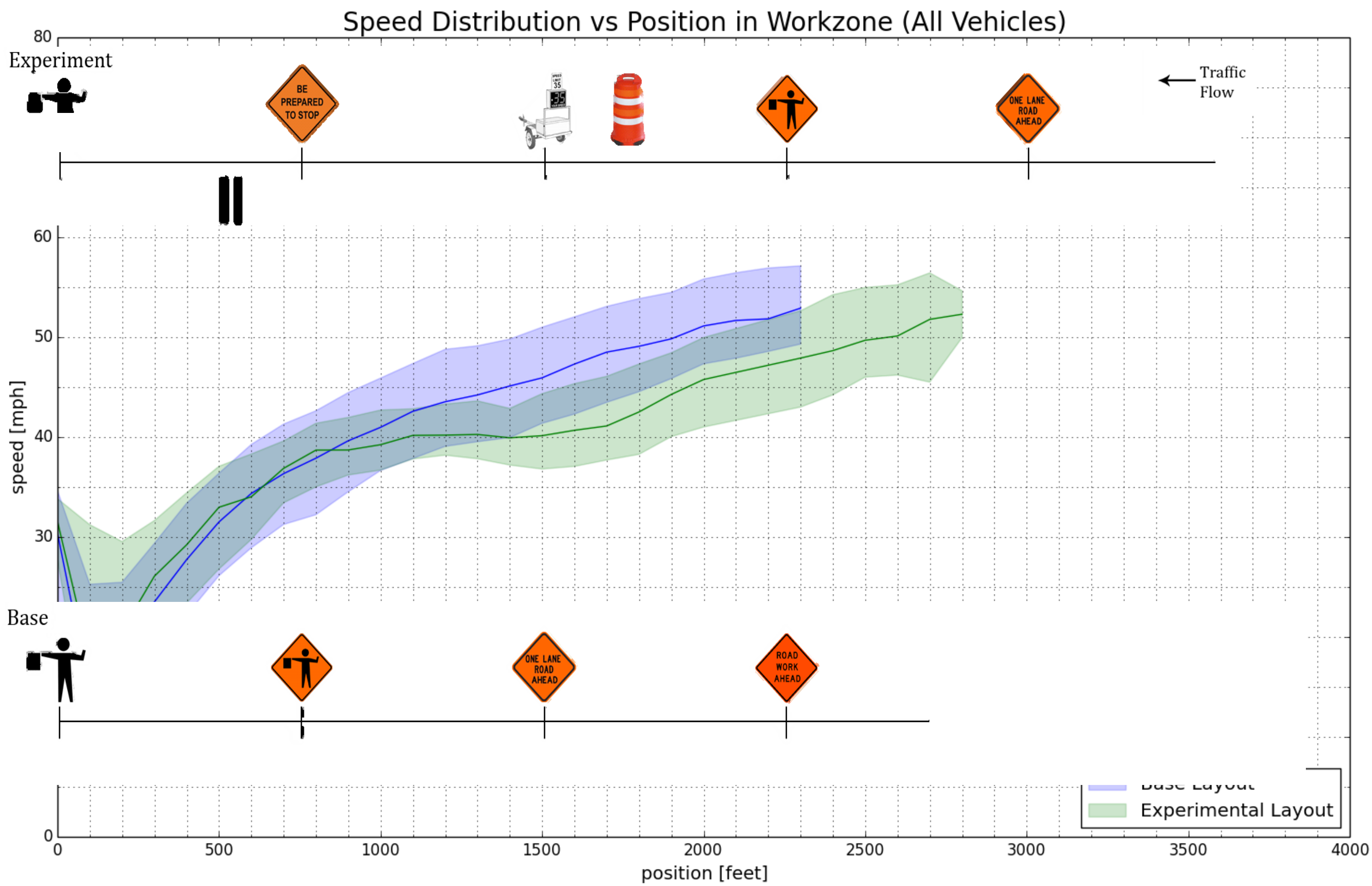

Figure 3.47 Speed distributions vs distance. All vehicles at 2014 (original) field experiment.

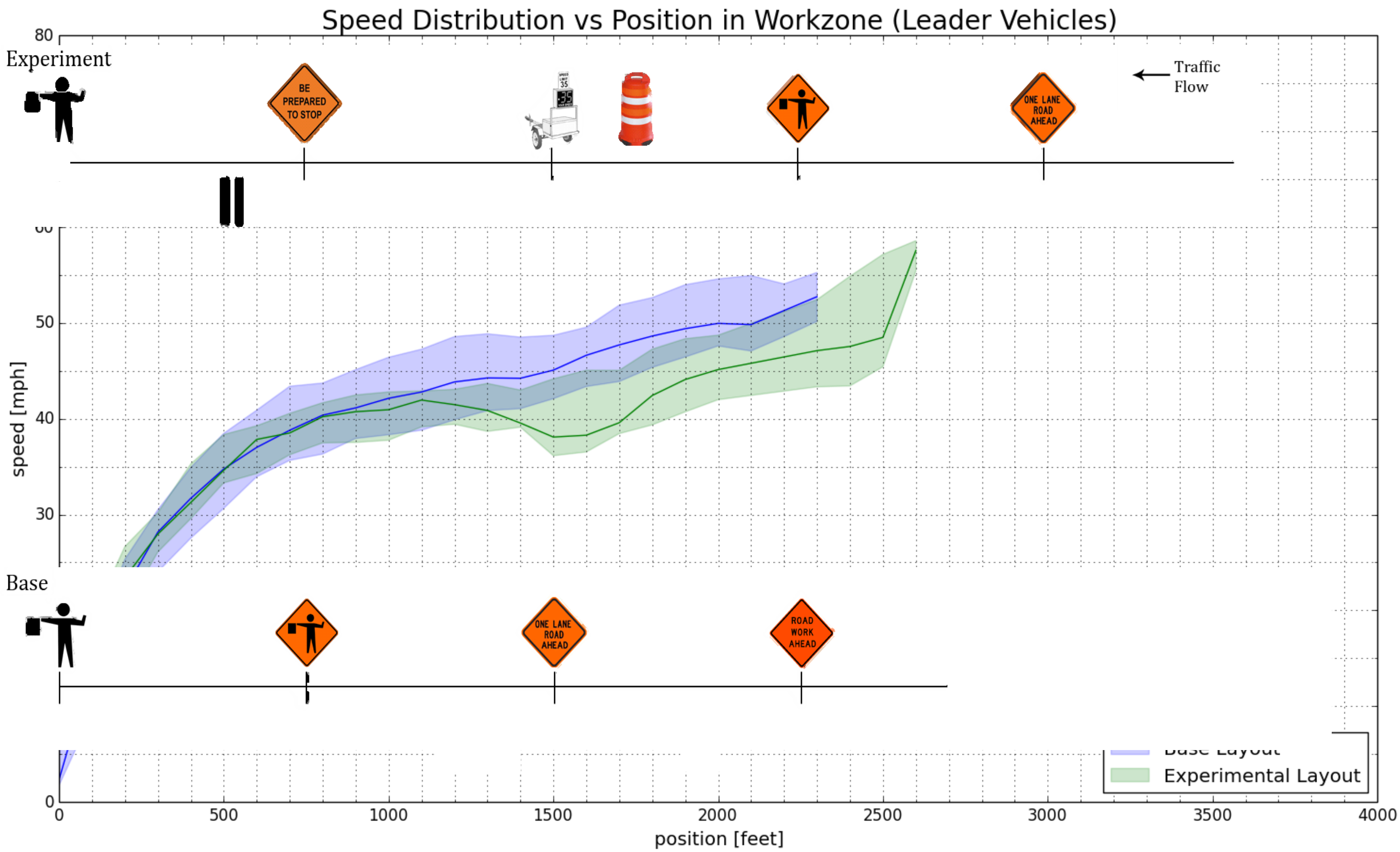

Figure 3.48 Speed distributions vs distance. Leader vehicles at 2014 (original) field experiment

3.12 FIELD STUDY CONCLUSIONS

The two field deployments of the experimentally identified new proposed traffic control layout in flagger-controlled work zones revealed that the speed trailer + horn successfully influenced drivers to reduce speeds, but the portable rumble strips did not. It is important to note, however, that an independent assessment of portable rumble strips was not within the scope of this study. Rather the portable rumble strips were included in a set of new treatments and were located downstream from the speed trailer + horn so drivers remained under the influence of the speed trailer + horn as they approached the rumble strips.

Because the combination speed trailer + horn spatially preceded the rumble strips the influence of the speed trailer + horn can be evaluated. Our findings reveal that the speed trailer + horn have a significant influence on a reduction in driver speed as well as the spread of the speed samples. As discussed earlier in this document, the experimental layout practically eliminated high speed outliers in addition to succeeding in reducing the approach speed to the flag operator.

CHAPTER 4: CONCLUSIONS

4.1 SUMMARY FINDINGS AND CONCLUSIONS OF THE DRIVING SIMULATOR EXPERIMENT

In this exeriment, we used a driving simulator to identify elements that capture and sustain driver attention in flagger-controlled work zones. We obtained lane position data and driving speed data from the 160 participants who drove the simulated rural highway three times. We were particularly interested in determining whether flashing LED lights mounted on the first warning sign of an approach to a flagger-controlled work zone contributed to more significant reductions in speed than the same sign without the flashing LED lights. We are also particularly interested in whether a horn blast emitted for drivers exceeding 45 mph on their approach to an intelligent speed limit display effectively captured the attention of outlier drivers. And we were interested in determining the effectiveness of transverse rumble strips as an attention-grabbing device in a simulated flagger-controlled work zone.

Our main findings are the following:

- The new set of elements is more effective than the elements currently used to reduce driving speeds on the approach to the flagger-controlled work zone;
- We found no difference in mean driver speed in response to the sign with an LED presence;
- The dynamic speed display coupled with the horn is more effective than the dynamic speed display alone;
- Survey responses provide helpful self-reported information from drivers.

4.2 SUMMARY FINDINGS AND CONCLUSIONS OF THE FIELD STUDY

The two field deployments of the new experimentally identified proposed traffic control layout in flagger-controlled work zones revealed that the speed trailer + horn successfully influenced drivers to reduce speeds, but the portable rumble strips did not. It is important to note, however, that an independent assessment of portable rumble strips was not within the scope of this study. Rather the portable rumble strips were included in the set of new treatments and were located downstream from the speed trailer + horn so drivers may have remained under the influence of the speed trailer + horn as they approached the rumble strips.

Because the combination speed trailer + horn spatially preceded the rumble strips the influence of the speed trailer + horn can be evaluated. Our findings reveal that the speed trailer + horn had a significant influence on driver speed as well as the spread of the speed samples. As discussed earlier in this document, the experimental layout practically eliminated high-speed outliers in addition to succeeding in reducing the approach speed to the flag operator.

4.3 OVERALL SUMMARY

The elements identified as effective in capturing and sustaining driver attention in flagger controlled work zones in the laboratory were then tested in a field study. The field study confirmed the findings of the driving simulator study. As noted above, our findings clearly indicate that the experimental layout was highly successful in practically eliminating high-speed outliers as well as in reducing the approach speed to the flag operator.

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APPENDIX A

A.1 Interaction effects on the approach to the first warning sign

There were three statistically significant two-way interactions affecting the average speed on the approach to the first warning sign. These interactions are presented in detail below:

A.1.1 Two-way interaction between age and gender

The interaction between age and gender on average speed was statistically significant with a p-value of 1.001e-08. The average speed data as a function of different age groups and genders are show in Table A.1 below.

Table A.1. Average speed as a function of different age groups and genders

Gender	Younger	Middle Age	Older	Senior
Female	55.99803	56.62247	51.94117	48.98100
Male	58.31047	55.59223	52.95057	51.83173

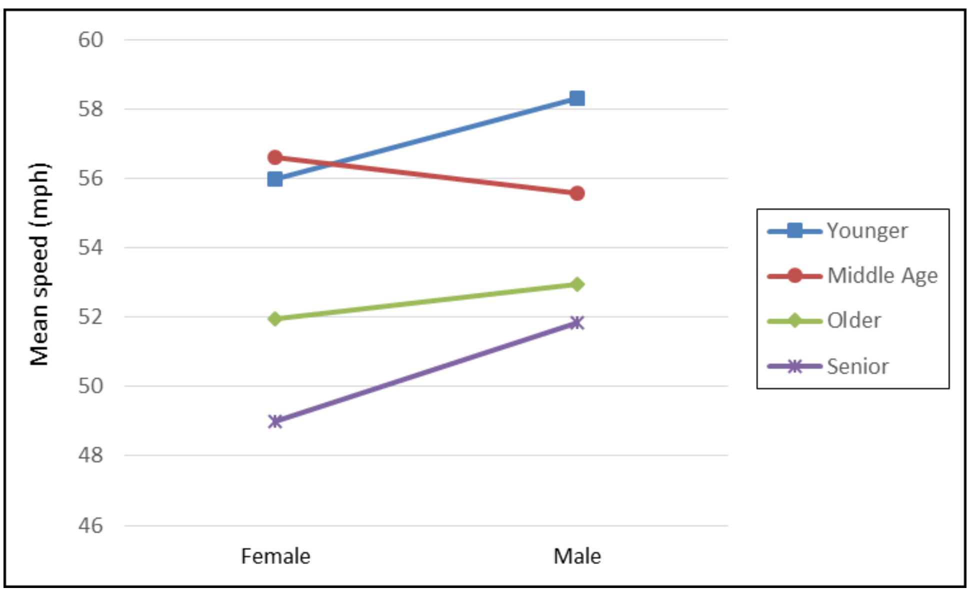

Figure A.1. Average speed of different genders for each age group

A.1.2 Two-way interaction between age and condition

Table A.2 Average speed as a function of different age groups and conditions

Condition	Younger	Middle Age	Older	Senior
Control	56.52945	55.85680	53.05765	50.70600
Non-LED/Horn	57.66605	56.39885	52.25645	49.14480
LED/Horn	57.26725	56.06640	52.02350	51.50150

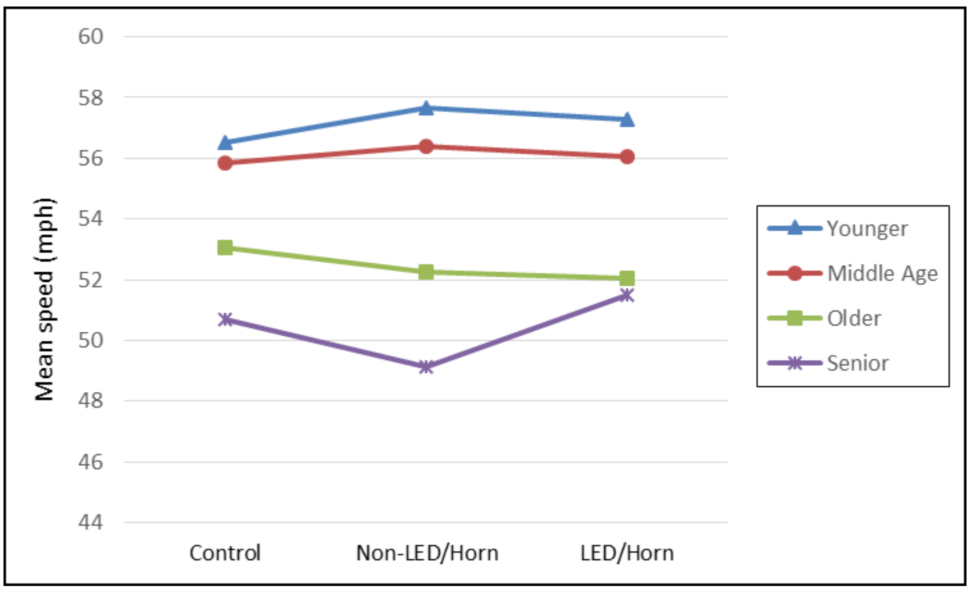

Figure A.2. Average speed of different age groups for each condition

A.1.3 Two-way interaction between age and segment

Table A.3. Average speed as a function of different age groups and segments

Segments	Younger	Middle Age	Older	Senior
Segment 1	58.23233	57.56933	55.04142	54.28717
Segment 2	57.87217	56.93500	53.84458	52.68400

Segment 3	57.23675	56.14233	52.55958	50.45767
Segment 4	56.57342	55.38200	51.17483	48.46067
Segment 5	55.85658	54.50808	49.60892	46.14233

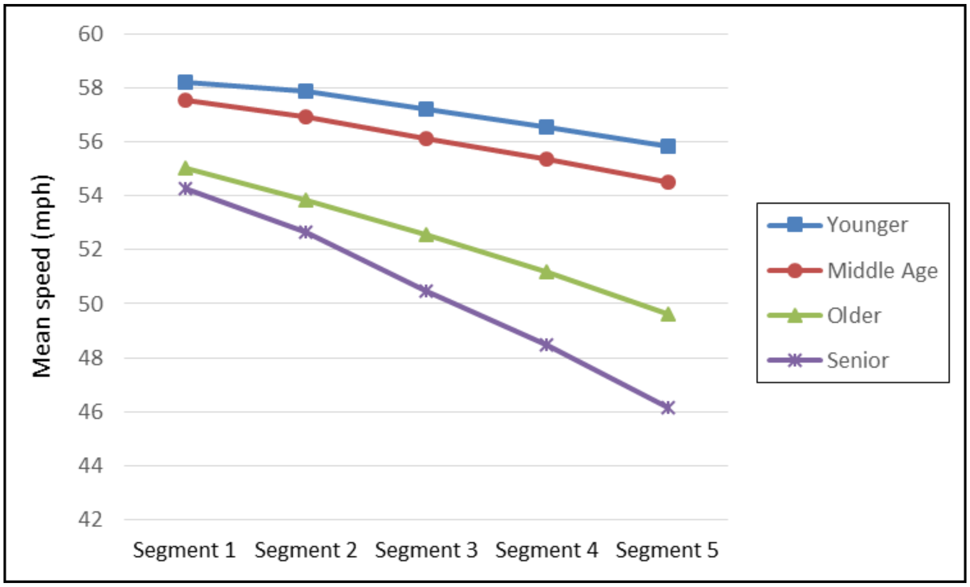

Figure A.3. Average speed of different segments for each age group

A.2. Interaction effects on approach to the second warning sign

A.2.1. Two-way interaction between age and gender

Table A.4. Average speed as a function of different age groups and genders

Gender	Younger	Middle Age	Older	Senior
Female	51.69992	50.69896	43.51175	39.20121
Male	52.91708	51.44687	45.99004	43.33692

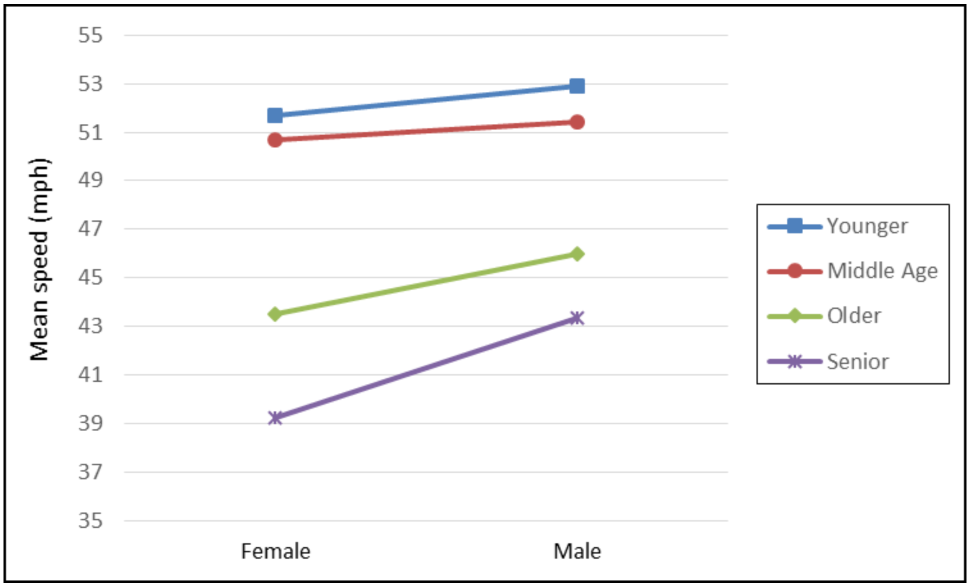

Figure A.4. Average speed of different genders for each age group

A.2.2. Two-way interaction between age and condition

Table A.5. Average speed as a function of different age groups and conditions

Condition	Younger	Middle Age	Older	Senior
Control	53.47787	51.69944	46.69800	43.27090
Non-LED/Horn	52.54588	51.81631	44.82350	39.40425
LED/Horn	50.90175	49.70300	42.73119	41.22481

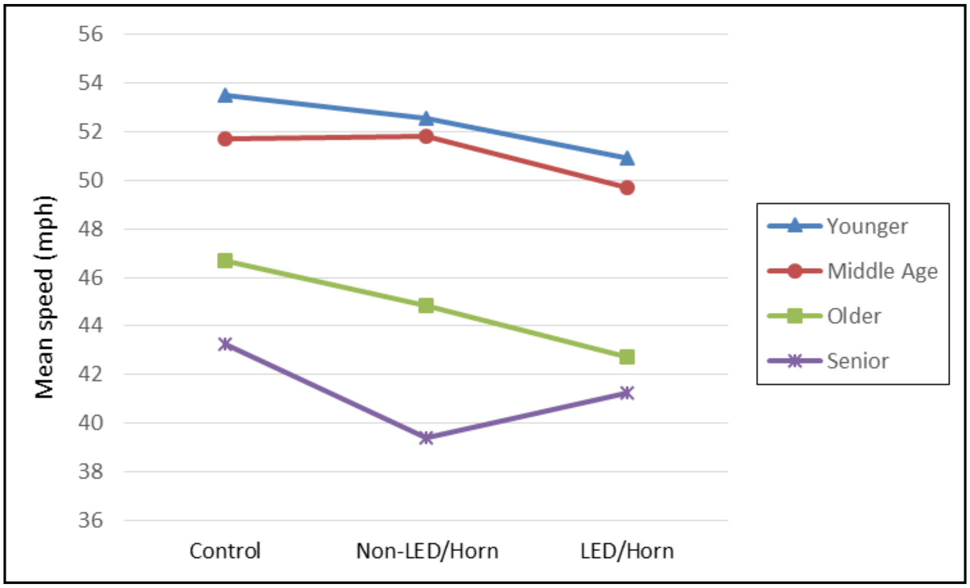

Figure A.5. Average speed of different age groups for each condition

A.3. Interaction effects on approach to the third warning sign

A.3.1 Two-way interaction between age and condition

Table A.6. Average speed as a function of different age groups and conditions

Condition	**Younger**	**Middle Age**	**Older**	**Senior**
Control	50.09531	49.72619	42.67319	38.49577
Non-LED/Horn	44.84875	44.07519	38.07419	35.06719
LED/Horn	43.66987	42.64375	37.37300	35.69375

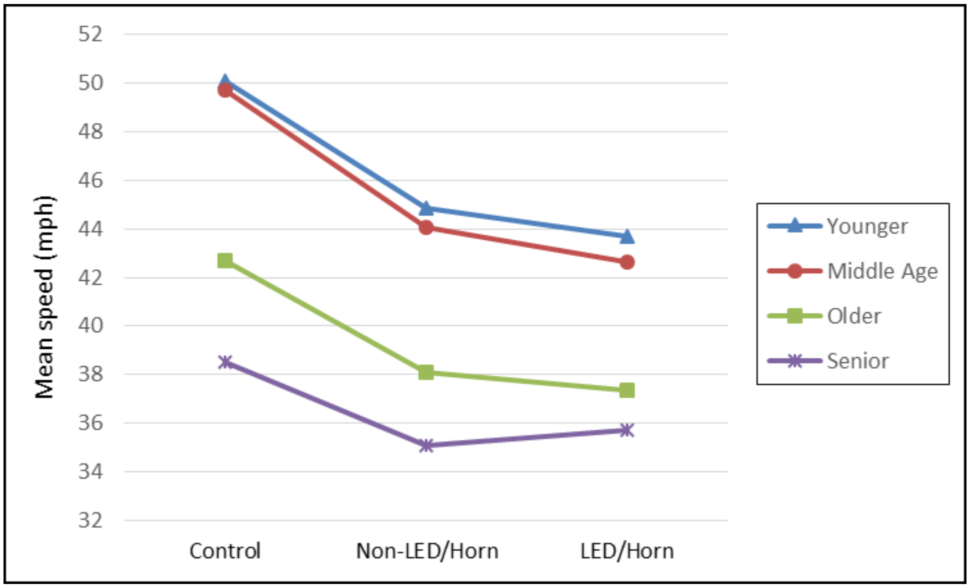

Figure A.6. Average speed of different age groups for each condition

A.3.2 Three-way interaction between age, gender and condition

Table A.7. Average speed as a function of age group, gender and condition

Gender	**Age group**	**Control Condition**	**Non-LED/Horn Condition**	**LED/Horn Condition**
Female	Younger	50.18512	43.70213	42.99750
	Middle Age	48.06450	45.18125	42.57550
	Older	42.01175	36.94013	36.12025
	Senior	37.27382	34.05138	34.52887
Male	Younger	50.00550	45.99538	44.34225
	Middle Age	51.38788	42.96912	42.71200
	Older	43.33463	39.20825	38.62575
	Senior	39.65662	36.08300	36.85863

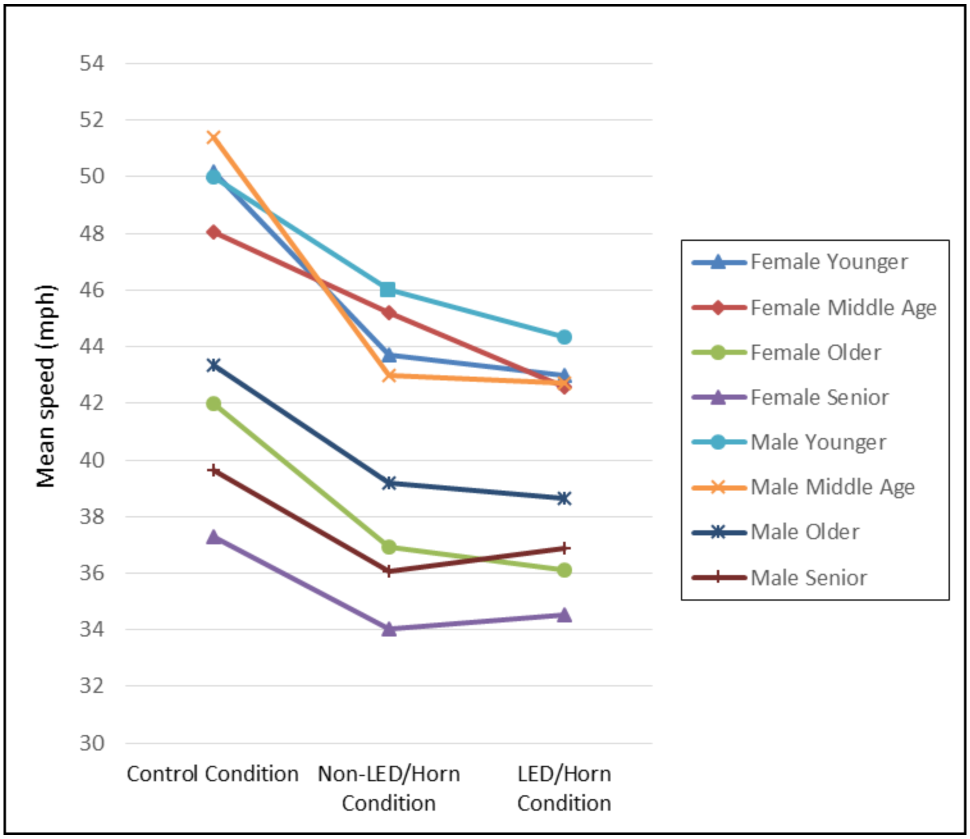

Figure A.7. Average speed as a function of age group, gender and condition

A.4 Interaction effects on approach to the fourth warning sign

A.4.1 Two-way interaction between age and condition

Table A.8. Average speed as a function of different age groups and conditions

Condition	Younger	Middle Age	Older	Senior
Control	45.62562	43.94537	35.93419	30.95974
Non-LED/Horn	40.09063	38.67006	33.65881	33.87687
LED/Horn	39.90937	38.32212	33.79256	34.37138

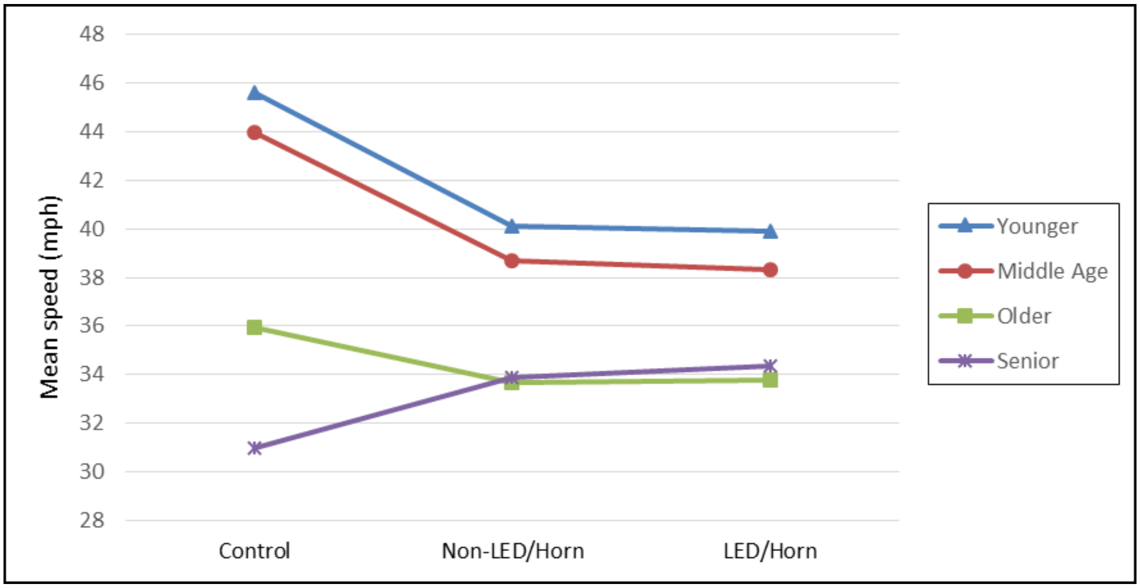

Figure A.8. Average speed of different age groups for each condition

A.5 Interaction effects on approach to the flagger

A.5.1 Two-way interaction between age and gender

Table A.9. Average speed as a function of different age groups and genders

Gender	Younger	Middle Age	Older	Senior
Female	27.88846	27.50979	19.61958	20.59062
Male	32.05271	27.54325	22.99554	21.97967

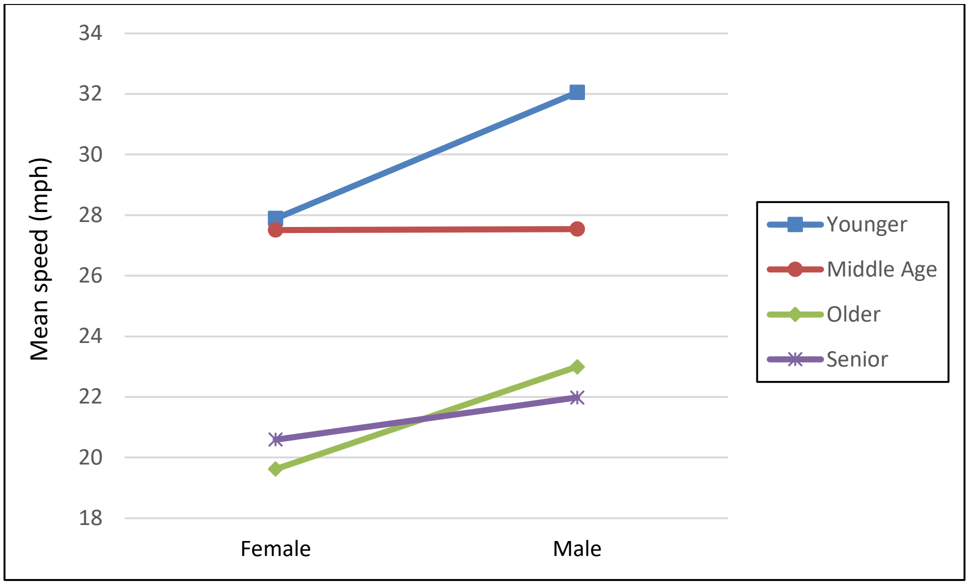

Figure A.9. Average speed of different genders for each age group

A.5.2 Two-way interaction between age and condition

Table A.10. Average speed as a function of different age groups and conditions

Condition	**Younger**	**Middle Age**	**Older**	**Senior**
Control	31.96181	29.53281	21.62675	20.42833
Non-LED/Horn	28.99387	26.74281	20.02419	21.24919
LED/Horn	28.95606	26.30394	22.27175	22.04750

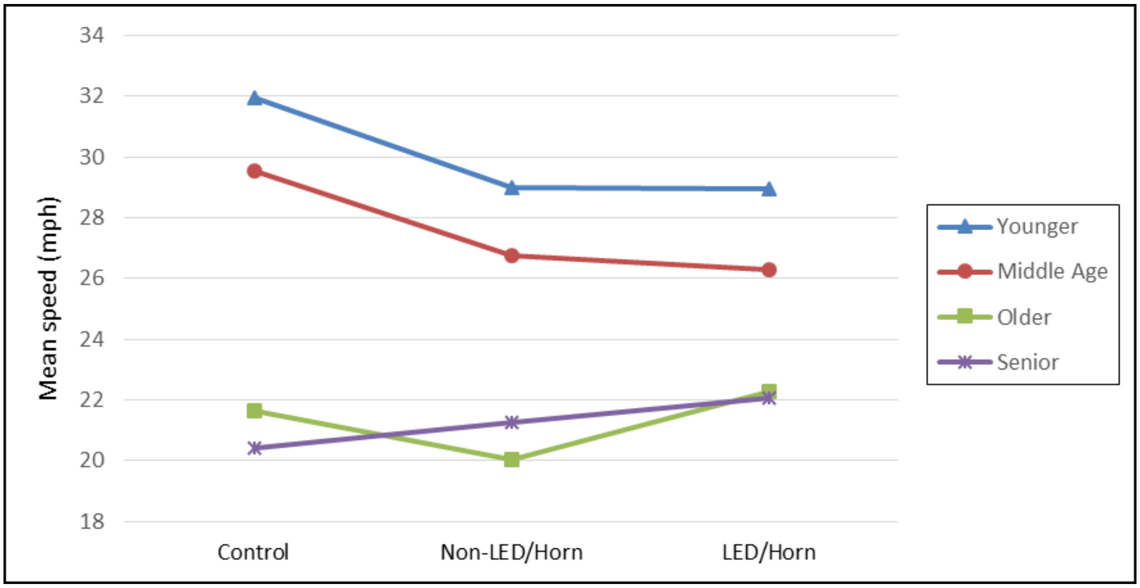

Figure A.10. Average speed of different age groups for each condition

A.5.3 Two-way interaction between gender and segment

Table A.11. Average speed as a function of gender and segment

Segments	**Female**	**Male**
Segment 1	28.86054	32.59625
Segment 2	26.11812	28.82196
Segment 3	21.13625	23.03750
Segment 4	19.49354	20.11546

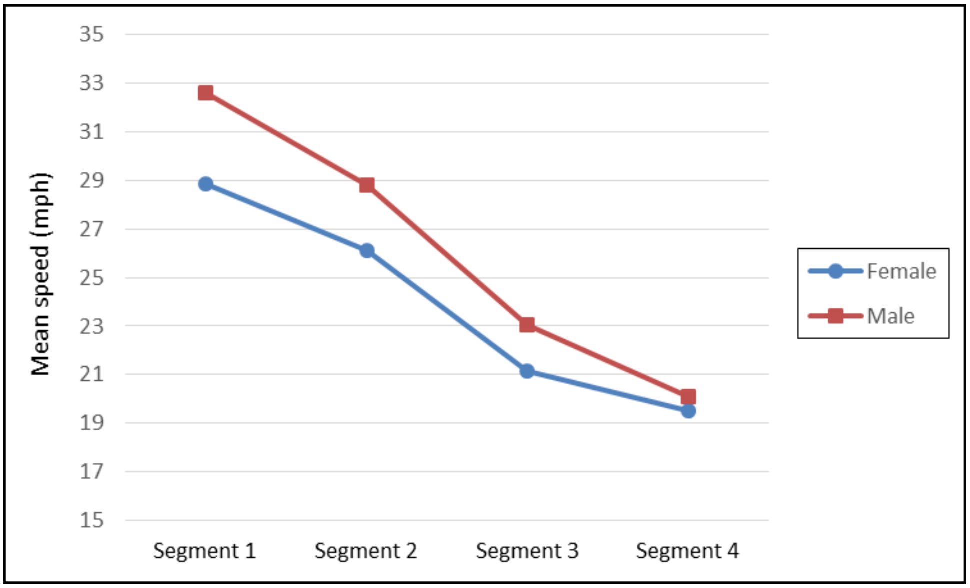

Figure A.12 Average speed of different genders for each segment

APPENDIX B

B.1. Driving speed trajectories by segment

The driving speed trajectories of each segment on the approach to each warning sign and the flagger are presented below.

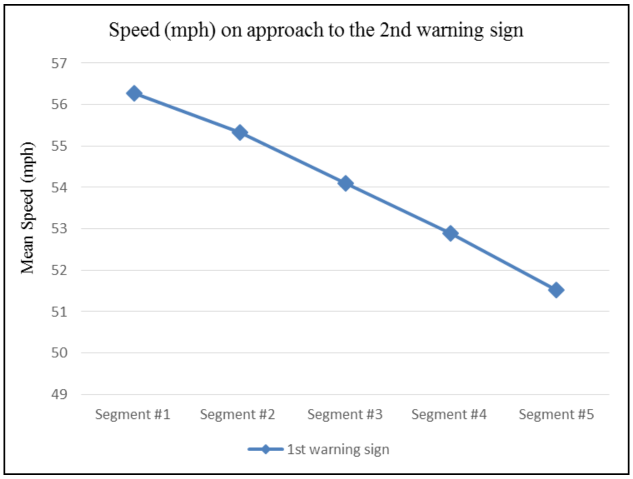

Figure B.1. Speed (mph) on approach to the first warning sign

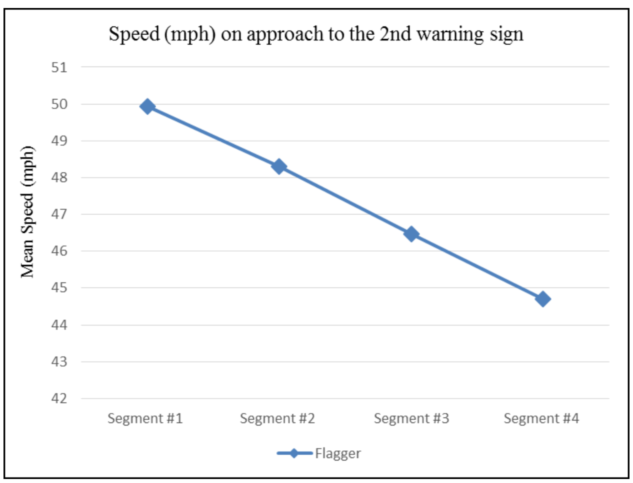

Figure B.2. Speed (mph) on the approach to the second warning sign

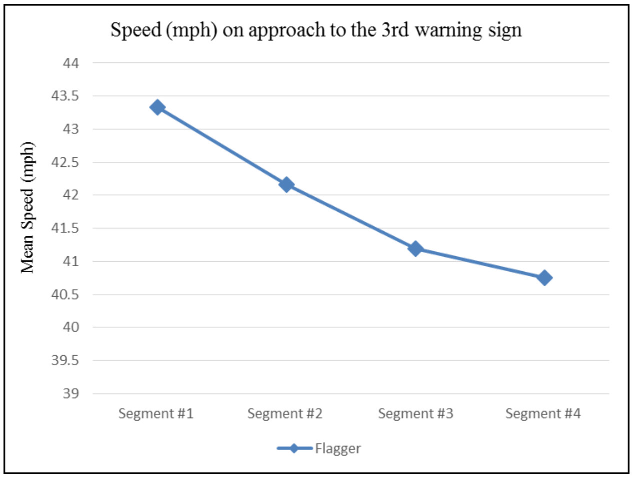

Figure B.3. Speed (mph) on the approach to the third warning sign

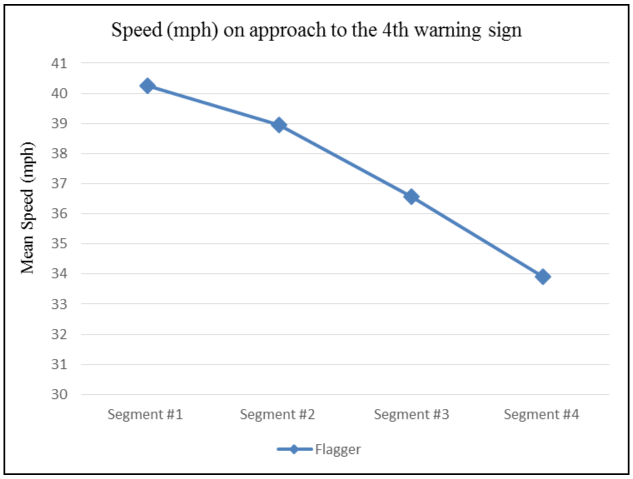

Figure B.4. Speed (mph) on the approach to the fourth warning sign

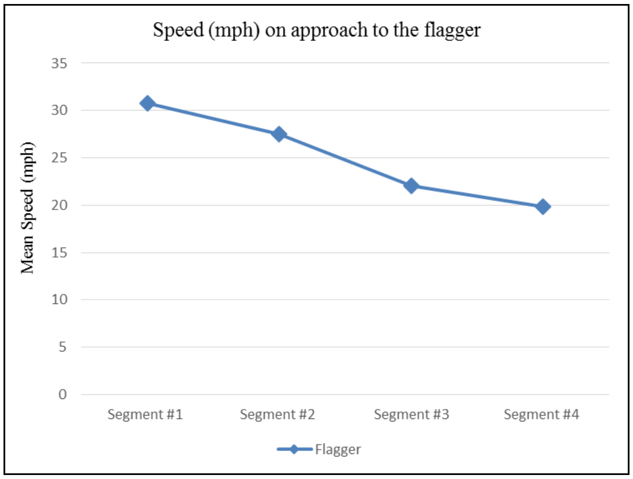

Figure B.5. Speed (mph) on the approach to the flagger

APPENDIX C

C.1. Survey Findings

After completing the three drives, the 160 participants were asked to respond to six survey questions pertaining to, for example, the extent to which they demonstrate consideration for other drivers, pedestrians, and bicyclists. The participants were also queried about awareness of road conditions while driving and whether they text while driving. For each question participants were instructed to select a number from 1 to 7 that best reflected their response to the question; a 1 reflected a response of "Never" and a 7 reflected a response of "Always". Though the survey was not the focal point of our research, and thus an extensive statistical analysis was not performed, the survey questions and descriptive statistics are presented question-by-question below.

C.1. Survey Question 1: *I demonstrate consideration for other drivers when I am driving.*

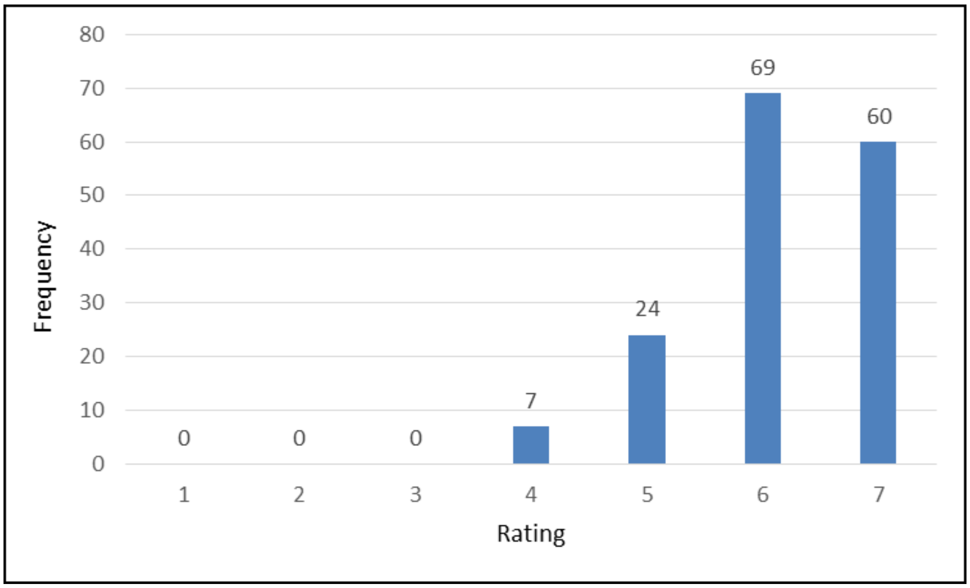

Figure C.1. Frequency distribution of responses to survey question 1. Mean response: 6.14 (SD = 0.83)

Table C.1. Mean response to Question 1 as a function of age group.

Question		**Younger**	**Middle Age**	**Older**	**Senior**
Q1	Mean	5.975	6.100	6.150	6.325
	SD	0.7333625	1.0076629	0.8335897	0.6938373

Table C.2. Mean response to Question 1 as a function of gender.

Question		Female	Male
Q1	Mean	6.1625	6.1125
	SD	0.8025868	0.8567491

C.2. Survey Question 2: *I feel obligated to be aware of road conditions when I am driving.*

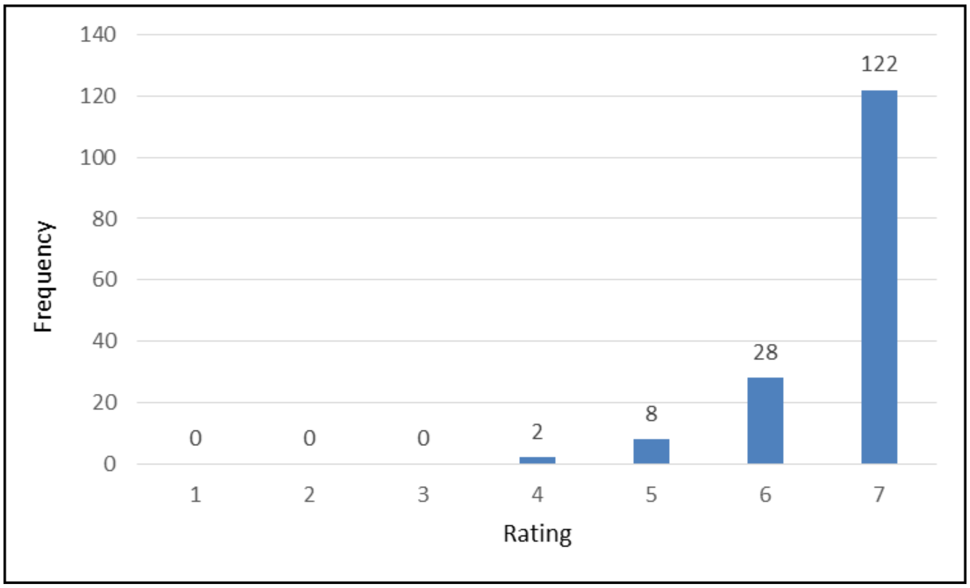

Figure C.2. Frequency distribution of responses to survey question 2. Mean response: 6.69 (SD = 0.63)

Table C.3. Mean response to Question 2 as a function of age group.

Question		Younger	Middle Age	Older	Senior
Q2	Mean	6.550	6.800	6.525	6.875
	SD	0.6774765	0.4050957	0.8766925	0.3349321

Table C.4. Mean response to Question 2 as a function of gender.

Question		Female	Male
Q2	Mean	6.6625	6.7125
	SD	0.6925234	0.5556101

C.3. Survey Question 3: *I demonstrate consideration for pedestrians when I am driving.*

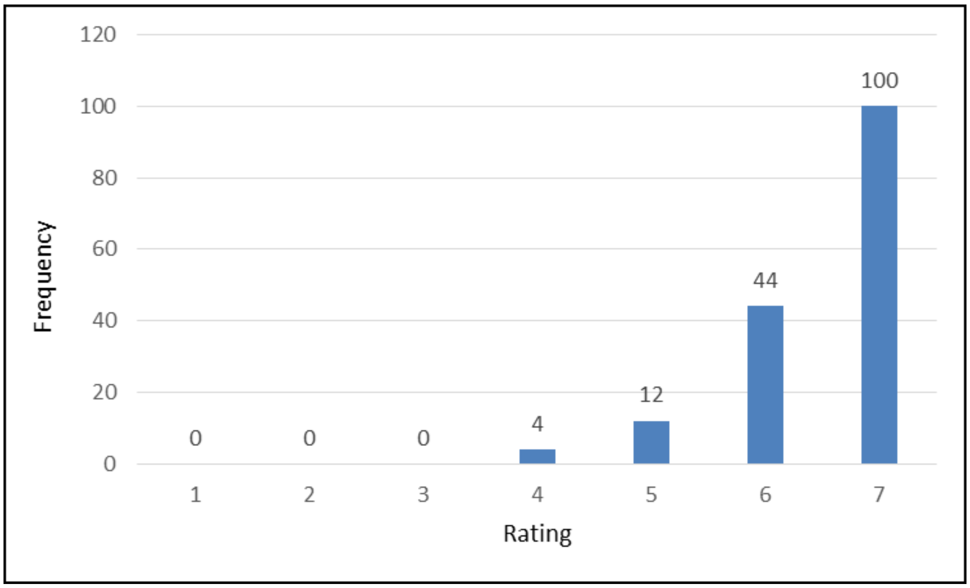

Figure C.3. Frequency distribution of responses to survey question 3. Mean response: 6.5 (SD = 0.74).

Table C.5. Mean response to Question 3 as a function of age group.

Question		Younger	Middle Age	Older	Senior
Q3	Mean	6.350	6.525	6.500	6.625
	SD	0.8638020	0.6788943	0.7510676	0.6674675

Table C.6. Mean response to Question 3 as a function of gender.

Question		Female	Male
Q3	Mean	6.5125	6.4875
	SD	0.7461929	0.7461929

<u>C.4. Survey Question 4:</u> *I demonstrate consideration for bicyclists when I am driving.*

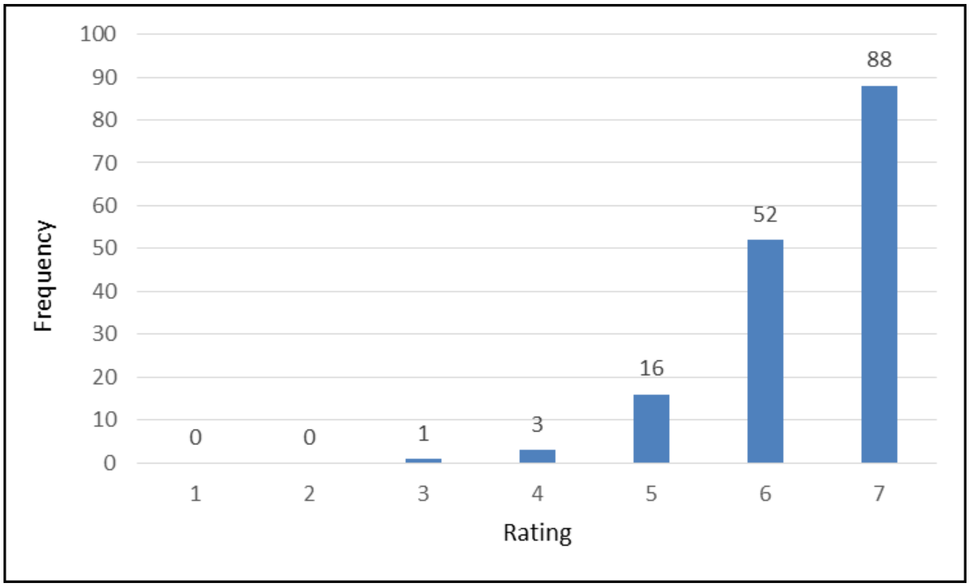

Figure C.4. Frequency distribution of responses to survey question 4. Mean response: 6.39 (SD = 0.79)

Table C.7. Mean response to Question 4 as a function of age group.

Question		Younger	Middle Age	Older	Senior
Q4	Mean	6.175	6.400	6.350	6.650
	SD	1.0594508	0.6717753	0.8022405	0.4830459

Table C.8. Mean response to Question 4 as a function of gender.

Question		Female	Male
Q4	Mean	6.4875	6.3000
	SD	0.7461929	0.8328691

<u>C.5. Survey Question 5:</u> *I text while I am driving.*

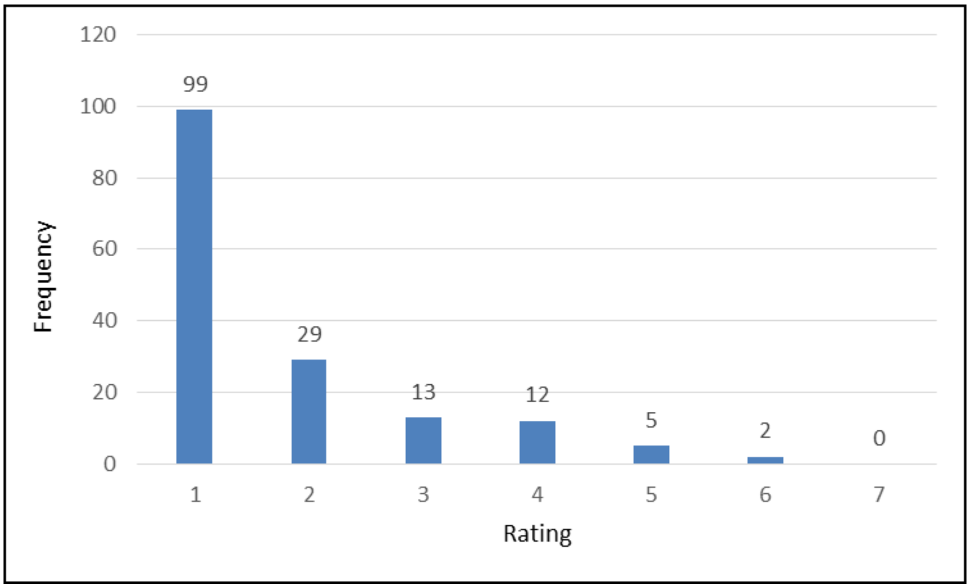

Figure C.5. Frequency distribution of responses to survey question 5. Mean response: 1.76 (SD = 1.196)

Table C.9. Mean response to Question 5 as a function of age group.

Question		Younger	Middle Age	Older	Senior
Q5	Mean	2.675	2.075	1.275	1.000
	SD	1.3471242	1.3085028	0.7156672	0.0000000

Table C.10. Mean response to Question 5 as a function of gender.

Question		**Female**	**Male**
Q5	Mean	1.6875	1.8250
	SD	1.175636	1.219826

C.6. Survey Question 6: *I trust that road signs are accurate.*

Finding:

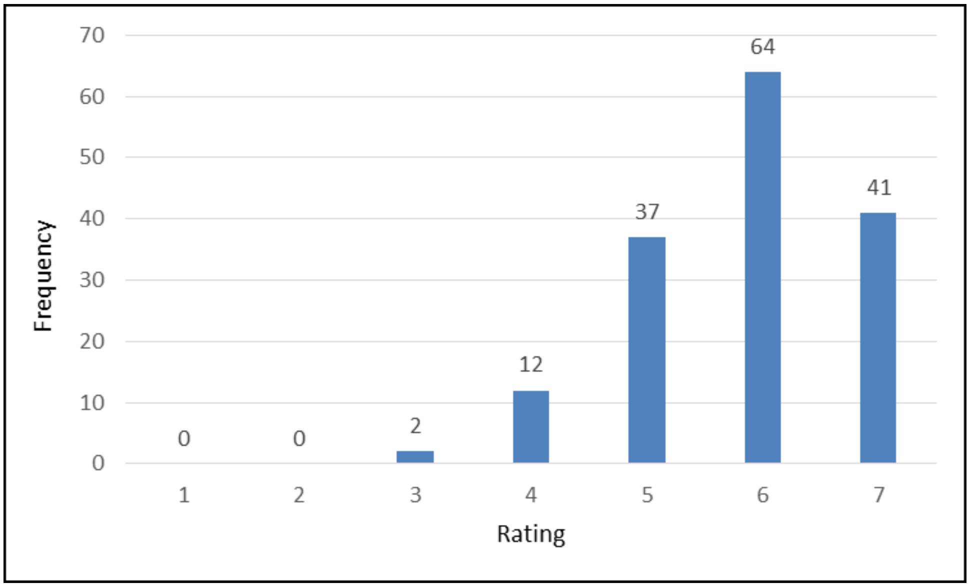

Figure C.6. Frequency distribution of responses to survey question 6. Mean response: 5.83 (SD = 0.95)

Table C.11. Mean response to Question 6 as a function of age group.

Question		**Younger**	**Middle Age**	**Older**	**Senior**
Q6	Mean	5.794872	5.657895	5.875000	6.000000
	SD	0.7670685	1.0469083	1.0666867	0.8885233

Table C.12. Mean response to Question 6 as a function of gender.

Question		**Female**	**Male**
Q6	Mean	5.936709	5.727273
	SD	0.8964570	0.9952038